COMPUTER AIDED FACTORY LAYOUT PLANNING

(CAFLAP)

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M I D D L E S E X   P O L Y T E C H I C

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Computer Aided Factory Layout Planning (CAFLAP)

A B S T R A C T

This Thesis addresses Factory Layout Problems, and reviews and evaluates the available layout techniques.

Manufacturing as a system has been studied and reclassified for factory layout: space demands and spatial relationships have been considered as main principles of Factory Layout Planning. This forms a basis for the introduction of a new, more efficient Factory Layout Planning Methodology, denoted as SPACE MANAGEMENT. A new COMPUTER AIDED FACTORY LAYOUT PLANNING system is formulated as a tool for:

- preparing 3-D templates of Work Station Modules and Equipment Modules;

- drawing a requested interior of an industrial hall/bay in 3-D;

- positioning any 'objects' (spaces), via manual interactive programs in 3-D;

- automatic positioning of work stations and equipment in the bay, in 'technological' order (in 3-D), using an automatic positioning program, with a facility for:
  - collision course finding (with objects within the bay),
  - manual override for corrections, and
  - finding an optimum size (width) of the bay.

The resulting layout scene can be observed from any required position and distance.

The system includes a set of auxiliary programs for Manual Feeding of lines of work stations in 'technological' order and for basic capacity calculations.

CAFLAP also opens a new way of economic evaluation of projects and alternatives.

CAFLAP is implemented in FORTRAN 77 and uses the Computer Graphics System PICASO.

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CONTENTS

1. INTRODUCTION

The purposeful arrangement of machine tools and equipment on the shop floor is of equal importance for competitive manufacturing as machining itself. It is very well documented in history how the wealth of nations grows as their manufacturing standards improve. A very good example of this is the Republic of Venice [7]. Manufacturing was one of the pillars of the Republic's success, and was so advanced that in 1474 it led to the enactment of the first formal patent law. The "heart of the state of Venice" was the Arsenal [24]. Here was also the largest centre of production and the greatest concentration of workmen before the industrial revolution. The plans of the Arsenal, founded in 1104, were in fact an early example of planned plant layout!

'Plant Layout' and 'Factory Layout Planning' are terms (see Appendix I-1) most commonly used for labelling activities concerned with a feasible location of manufacturing or processing facilities in a suitable region, site, complex of buildings, industrial hall and finally in an industrial bay.

By definition, 'Plant Layout' is the most effective arrangement and coordination of the physical plant facilities, to allow greatest efficiency in the combination of man, materials, machines and equipment necessary for the operation of any unit of a plant or business [1]. The activity in Factory Layout Planning could be expressed symbolically as in Fig.1.

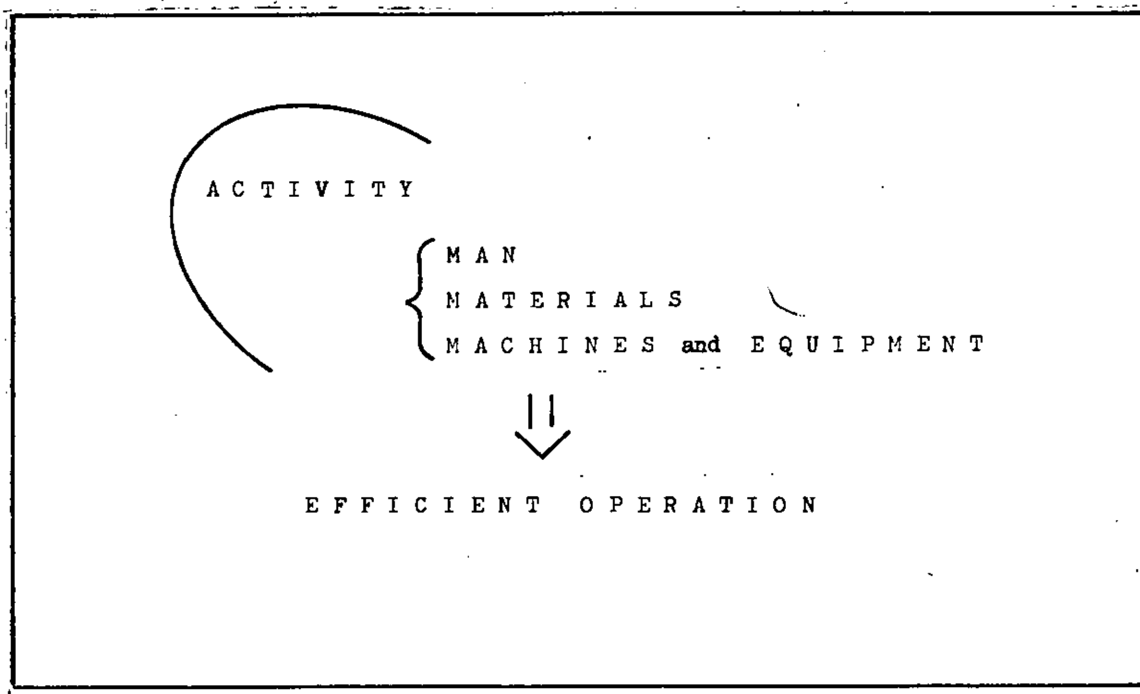


Fig. 1. ACTIVITY IN FACTORY LAYOUT PLANNING RESULTS IN EFFICIENT OPERATION

As the main interest of this project is focused on mechanical engineering manufacturing, the term Factory Layout Planning [22] has been chosen. This term also clearly distinguishes activities in mechanical engineering production from chemical and other similarly specialised plants (i.e.food processing, earth products etc.), and from the design of individual equipment.

Factory Layout Planning is closely interrelated with

Mechanical Engineering, Production Engineering, Mechanical Technology, Material Handling, Management and Organisation, Industrial Psychology and Sociology, Civil Engineering, Architecture and Town Planning on one side, and with Ventilation and Heating, and Electrical Engineering etc., on the other side. The requirements and demands of these professions together with legislative measures like the Health and Safety Act, and the regulations of the Ministry of Defence, Ministry of Transport and Civil Aviation can be very restrictive. Further factors related to the protection of nature, springs and water, historic monuments, etc., have to be carefully considered, and can sometimes even become ruling factors in Factory Layout Planning. All that is indispensable, as the construction of a new plant or modernisation and reconstruction of an older factory may have a substantial influence on the environment and on the lives of the inhabitants within a relatively large area.

In Factory Layout Planning there are usually two main types of situation to be encountered:

- The change of layout within an existing factory,

or

- A layout for a new factory on a 'green field site'.

In the first case the object is to try to utilise the existing areas in the most economical manner in order to accommodate efficient production. In the second case, the civil engineering part can be designed to fit exactly the technological needs. These two different situations can result in a different emphasis in layout techniques.

Other situations and complications follow from the type of manufacturing/production (single product, multi-product, parallel) and from the further division of production according to the quantity of products to be manufactured e.g.job production, batch production, flow production and mass production.

The type of production usually conditions the type of layout, i.e.:

- Process (or Functional) Layout,
  where the main factor for work stations arrangement is considered to be the technological process (similarity of operations, e.g. drilling machines in one area, milling machines in another area, etc., often creating departments, i.e. milling department, drilling department, etc.).

- Product (or Line) Layout,
  where the main factor for work stations arrangement is the product. Work stations are arranged to suit the sequences of operations (e.g. prodn. line). [1]

  As a special sub-group could be considered Group Layout (Group Technology and Flexible Manufacturing Systems).

- Fixed-Position Layout,
  where the product is stationary and material, men and equipment are brought together to work on the product (ships, bridges).

The initial considerations and calculations for new layout very often form the basis for the long-term prosperity of the whole company. A plant must be profitable and and the profit must be maximised, so that the plant layout /consulting engineer has to approach the task with this in mind and take care to avoid any possible losses in future, which may affect not only the investor, but the public as well. Therefore the future situation must be assessed already in the preliminary stage.

Here the layout engineer faces a dilemma. At this stage he is not in possession of sufficient amount of data and information of requested accuracy and depth to design a new layout. But still, the decision making must be as precise as possible. In some cases even the most essential information, e.g. the volume of production, is lacking and must be acquired by the engineer via an analysis of statistics, typical products, indirect indicators, and qualified guesses. The technique of Typical Products is used when there is a lack of information regarding the future actual products. Typical products have similar specifications and characteristics to those of the future planned products.

As this is a very demanding exercise, some companies and consulting engineering firms have developed up to five stages of project to avoid losses. For example, the Ford Motor Company has three 'project' stages: Programme Study, Study, and Project.(This will be dicussed later in Chapter 2.)

In this complicated situation it is quite difficult to find a way to ease the work of the Factory Layout Planning Engineer. According to Francis and White [16] (published in 1974!) there were some five hundred papers written on the topic.

Moor in his survey [30] in the same year (1974) analysed twenty five programs and concluded that the layout planner must still do almost all the adjustments. He considered the facility design problems to be complex and ill-structured, and as such they were handled in a variety of ways, such as: total enumeration, computerised techniques, interactive programming, heuristic programming and by intelligent machines. He also observed that a great majority of programs fell into the construction or improvement class, only five programs were found to fit into graph theory or other[30- Fig.3].

Lewis and Block [32] in 1980 noted that 'despite much research activity there is widespread failure to use available computer programs for planning the layout of manufacturing facilities'.

According to Lewis and Block this happened for two reasons: opinion that an experienced planner can produce acceptable layout based on his own subjective judgement; and ignorance of the potential benefits of computer-aided techniques.

The writer's own experience from Ford-Dagenham, Plant Layout Department (1973-75) was similar to that of Lewis and Block, but the reasons for the failure to use computer programs are seen differently. There were serious attempts made at Ford's to use the programs available at that time, but these failed to help efficiently in practical plant layout work. The main reason could be seen in the fact that the programs were covering only a tiny portion of the planner's tasks. The manual method of templates on 'skins' (see Appendix I-12) continued in use instead, until 1987 as documented by Mike Farish [33] (See Chapter 3.).

In the second half of the seventies the number of published work titles on Factory Layout Planning seems to have dropped. However between 1980 and 1988, there were over forty new titles in the field (according to Applied Science and Technology Index, January 1980-March 1988). Contrary to Moor's survey findings and his classification [30] it seems that some entirely new aids are now appearing combining simulation and computer graphics, for example Hollocks [25]; and interactive computer graphics, for example O'Brien and Barr [34] (See Chapter 3.).

The present work introducing Computer Aided Factory Layout Planning (CAFLAP) also uses interactive computer graphics principles. Moreover CAFLAP is pioneering some new principles of layout planning (3-D space management), which are used in combination with computer graphics in order to assist the layout engineer in a more creative way mainly in detailed layout planning.

CAFLAP offers planners a very simple, cheap and easy-to-learn-and-use practical tool for everyday layout work; a tool which would be always available for any production engineer or planner to use as and when the need occurs.

2. FACTORY LAYOUT PLANNING AND EXISTING TECHNIQUES

2.1 FACTORY LAYOUT PLANNING

According to Reed [1] a good factory layout should satisfy the following basic requirements:

- Improvement of the manufacturing process
- Improvement of Material Handling (M.H.)
- Most effective use of available area
- Improved utilisation of labour
- Improved efficiency in plant services
- Improved employee morale
- Improved production management, quality and production control
- Minimum capital investment

Main objectives of a good layout could be formulated from experience, using the above as a lead:

- effective and safe operation
- comfortable and safe access to work stations for operation and maintenance
- straight Material Flow
- work stations as close to each other as possible
- work stations positioned in inter-related positions (in straight lines or groups)
- work stations in positions requesting minimum space

in an industrial bay

and

- work stations in positions with no interference with other 'spaces' (see 4.2, 4.3 and 4.4).

Observing the situation in Factory Layout Planning Bestwick and Lockyer [3] conclude that "there are a number, and sometimes conflicting requirements, which should be satified" if "most effective arrangement and co-ordination of physical plant facilities" is to be achieved.

In the writer's view there are two different categories of basic requirements': conflicting and complementary.

Considering first the complementary criteria it can be seen that:

Firstly, improvements in the manufacturing process can be achieved if in the layout planning area provisions are made for smoother material flow and reduction of delays. This, projected on the shop floor, can be achieved by improved Material Handling (M.H.). The main generally recognised principle of M.H. is DON'T (i.e.don't move). Apple [35] and others are stressing the importance of elimination of movements. If movements cannot be eliminated they should be simplified, shortened and straightened. Any congestion should be avoided.

These M.H. principles are in agreement with the requirement for closeness of facilities as formulated by Muther [4]. The principles of closeness and reduction of movements are aimed at greater cost effectiveness.

Shorter distances between facilities result in improved utilisation of labour, not only in the M.H. area, but also in manufacturing services; e.g. faster supply of tools (this depends on accessible positioning of Tool Crib).

Secondly, closeness of sufficient facilities for health and welfare (lavatories, drinking water, sitting facilities, rest rooms, etc.) in connection with Health and Safety at Work requirements [36,57] eliminates the excessive Relaxation Allowance [51] and improves the quality of relaxation time for the labour force. These measures directly contribute to employees' contentedness, and this improves their moral. The aesthetic effect of well arranged layout also makes an all round positive contribution.

Thirdly, closeness of facilities is complementary to the requirement of the most effective use of the available (or designed) area, therefore the yield of shop floor space (t/m sq., number of products per m sq., etc.) may be increased. This positively influences capital investment which can be minimised, especially in 'green fields' projects. Size of buildings, and therefore cost of buildings, could be reduced with consequent reduction of cost of maintenance, reduction of cost of heating, ventilation, lighting and other overheads. The resulting compact layout is more controlable and therefore supports in a better way production management functions; management control, identifying and counting of W.I.P. and products is simplified.

Fourthly, from operation management and utilisation of labour point of view, the achievement of the proper plant layout allows the most effective design of individual operations, the process and the flow.

Fifthly, the achievement of a proper facilities layout incorporating correct inspection locations in the process should positively influence quality control.

Sixthly, layout planned for ease of maintenance allows for the use of maintenance time effectively and reduces personnel requirements.

All of the above complementary criteria show the profitable advantages of proper Factory Layout Planning.

Contrary to this, are conflicting combinations of criteria, which are making the task of the layout planner more difficult. The sources of conflicts occur among the needs of production technology, space requirements, space available and the overriding economic criteria.

Firstly, a conflicting situation may arise between the requirements of an ideal technological position of work stations and the real space of an industrial hall/bay.
For example, a sophisticated calculation [5,6,7,8,9] can recommend positioning work stations in a cluster to achieve the shortest possible distances between them. Theoretically this seems to be a perfect recommendation, but it could prove an unacceptable one if the width of the existing industrial bay cannot accommodate the cluster! In the same way the cluster arrangement may conflict with the spatial demands of Material Handling.

Secondly, a conflict may also arise with the width of the bay when a group or line arrangement of work stations, each of which has a different size, has to be accommodated.

Thirdly, different sizes of work stations in recommended positions may conflict with the requirements for the most economic utilisation of the shop floor area. There could also be a collision of work stations with supports/columns of maintenance steelwork etc.

Fourthly, the interrelated positions of departments, services, stores, tool cribs and the relative positions of foremen, etc., could be sources of conflict.

In order to achieve the best possible results in the final layout it is essential to compromise and establish priorities. But priorities could vary from case to case and from planner to planner.

From the point of view of overall economy, it is the distance between the interrelated places that plays the main role. It was probably for this reason that most research effort has so far been concentrated on understanding the flow of material, in an attempt to shorten the distance of travel of Work in Progress (W.I.P.) between operations. A number of methods and relationship charts, studying mostly 'from - to' material handling, have been developed. The most widely recognised method is Muther's [4] Systematic Layout Planning. He also gives priority to the closeness of facilities, combined with the importance of relationships among facilities, rated by a unique AEIOUX rating system.

These techniques improve the quality of the layout engineer's work, but have very little impact on his productivity. New ways have only been opened by the wider implementation of computers (see Chapter 3.).

As already mentioned in Chapter 1., each project is usually divided into several project stages. Reasons could be found in the necessity of approval procedures for financing the project, strategic planning, regional planning etc., as well as in technical methodology of approximation, i.e. from theoretical outline ideas of the system, to detailed complex design and installation of the "recommended system" [4, 40].

Another category in Factory Layout Planning are design phases. These are logical steps in layout design methodology and could be seen represented by some well known procedures like Muther's Systematic Layout Planning, Apple's Plant Layout Procedures or Reed's Plant Layout Procedures as summarised by Tomkins and White [39].

The distinguished reality of project stages and design phases as parallel categories is unfortunately not stressed enough in Factory Layout Planning literature. Very often they are intermixed. But for the sake of methodological clarity this should be avoided.

The distinct differences between project stages and design phases could be seen clearly from the following definition and description of project stages; which is then followed (for comparison) by design phases.

Definition of project stages:
Project stages (see Appendix I-2) are graded steps in the preparation of project documents (i.e.reports, calculations, drawings etc.). Each step gradually goes into more depth and detail of factory layout.

In an ideal situation engineers would have the capacity, the time and the information to solve detailed problems in the early stages, as these could often influence the final economic aspects of the project.

To see more clearly the extent of the problem it is useful to describe in outline the project stages:

Stage 1.

FEASIBILITY STUDY (see Appendix I-3) defines the most economical approach to the plant layout. The production programme should be defined at this stage, sometimes with the help of typical products. The main Flow of Material, the number of machines and equipment needed, and the main areas and building(s) required should be established here, as well as manning and services. In drawings main areas and buildings are presented as block layout. A programme of all building and layout works and with the relevant economic considerations should be worked-out. Two or more alternatives are usually considered.

Stage 2.

INVESTMENT PROJECT (Appendix I-4)

studies the size of the main industrial hall(s), dimensions of bays and annexes of the plant; determines the requested production programme and flow of material; designs departments in inter-related positions, but without detailed shop floor layout and the positions of work stations and equipment. In drawings the departments are often presented as more accurately specified block layout. In the case of a new factory on 'green field', a site is selected. As above, two or three alternatives are usually considered.

Stage 3.

PROJECT and WORKING DRAWINGS

In this final project stage (Appendix I-5) all final 'capacity' calculations are made, work stations (machines and equipment) are determined and their positions are fixed in the layout of the defined building.

The project layout drawings show e.g. work stations in realistic shape, with details like anchoring bolts, and position of power supply, electrical accessories, connection to gas, water, coolant supply, etc. The Working Drawings (Appendix I-6) include all the details necessary for work stations installation and any necessary civil engineering works, e.g. if foundations are requested. The industrial halls are positioned in the general layout.

In some commercially and technically complicated cases intermediate stages are introduced, usually after the Investment Project. For example, in an 'Introductory Project' (Appendix I-7) almost everything is defined exept the final and exact position of work stations inside the industrial halls. The intermediate stage is also used when the project and detailed final drawings are prepared in another country where the project is located and local subcontractors are employed. In this way the investor is saving on the cost of design work, using local draftsmen and engineers. He only hires the experts from the consulting firm or supplier who designed the previous stages of the project. The experts, consulting engineers, supervise local staff and advise on site. This helps to secure higher employment for local people. The experts also pass on the 'know-how', which is very valuable especially for the 'Third World' countries.

\Design phases (represented here by Muther's Phases of Systematic Planning [4]) are following:

Phase I

LOCATION

Determine the location of the area to be laid out.

Phase II.

GENERAL OVERALL LAYOUT

Establish the arrangement of the area to be laid out.

Phase III.

DETAILED LAYOUT PLANS

Locate each specific piece of machinery and equipment.

Phase IV.

INSTALLATION

Plan the installation, seek the approval of the plan, make the necessary physical moves.

To illustrate the difference : In Feasiblity Study it is not necessary to use all design stages. Overall layout or a block layout in drawing presentation is all that is needed. In the Investment Project the situation would be similar.

The difference in the position of 'Location' in project stages and design phases can easily be seen. Muther [4] places the 'Location' first, while the present work places the 'Location' in project stages, in Stage 2. - Investment Project.

The approach here is different for the following reason: Prior to the selection of any plot or place (location) the main capacity calculations, requirements of areas, and a block layout of facilities have to be completed. The engineer responsible for the selection of a plot must have this information in hand together with details of max.loads (bearing loads) etc., otherwise the selection of the plot cannot be carried out with full responsibility. Not furnishing the information to the engineer could be costly: completly inadequate plot could be selected, which could result in expensive alterations e.g. foundations of heavy machines and building columns might have to be supported by piles etc..

Hence project stages are influencing the activity in design phases. This is apparently the reason why Tompkins and White ([39] - Fig 1.1) are putting their Facility Location in facility planning hierarchy on a completly independent level and position.

Further, in contemplating the design methodology and procedures only, for every layout, Muther [4] lays down three fundamentals:

Relationships - the relative degree of closeness desired or required among things;

Space - the amount, kind and shape or configuration of the things being laid out;

Adjustment - the arrangement of things into a realistic best fit.

The above three fundamentals have a special place in CAFLAP development.

In CAFLAP, the relationships are seen in dynamic and spatial terms (see 4.2).
From the production point of view, the dynamic/activity relationships are expressed in the 'technological' positioning of work stations to suit best the Flow of Material (requirements of the most economical production).

With the help of Nugent, Wollman and Ruml's [38] ideas, 'Technological' positioning can be defined as the optimal specification of which facilities are to be adjacent in the final layout without regard to the area or shape of the individual facilities.

The spatial demands are seen as the total amount of spaces to be accommodated in the building, which include the space needed for work stations and equipment, and some other spaces.

NOTE:

Here and in the rest of the thesis the terms 'space' and 'spaces' are used. In 3-D CAFLAP connotations (contrary to Muther's [4] spaces which are actually 2-D areas) they have been used to express the situations and spatial relationships (see 4.2).

The arrangement of work stations and equipment in the 'technological' order and realistic spatial position in an industrial bay, is the main task in Factory Layout Planning. Here also lies a source of conflicting situations and requirements, as dicussed above, and more:

Firstly, the work station itself has to be designed as a safe and comfortable place allowing and supporting all functions of the machine tool or equipment, and effective work of the operator(s). The design itself carries conflicts between safety and the requirements for most effective operation.

Secondly, the requested position of work station in the real space (building) could be in conflict with maintenance requirements.

Thirdly, the requirement for closeness of facilities could be a trigger for collision among functions, operations and maintenance of other facilities.

CAFLAP has been developed with all this in mind (see Chapter 4.).

2.2 EXISTING TECHNIQUES USED

For the study and design of Activity Relationships and the Flow of Material, a number of methods, mostly charts, have been in use (e.g. From-To charts, REL charts etc.).

On the basis of these charts, in relation to 'technological' (Appendix I-8) positioning of work stations, some computerised methods have been developed. The most important of them are discussed in Chapter 3.

From the point of view of graphical presentation of the arrangement of work stations in work shop situations the Space Relationships are the most important. Here below are outlined the main techniques for design of Space Relationships as historically developed, and as also presented even in the most recent literature ([39]-published in 1984 and [58] published in 1985).

Originally ordinary 2-D drawings were used for Factory Layout Planning. Work station after work station, position after position, had to be drawn individually. This often meant repeating similar shapes and situations, in the same way as in the days of the Venice Arsenal, or in the manner of Michelangelo Buonarroti's civil engineering layouts. There were no facilities to ease the draftsmen's work. This demanding and slow technique was improved by the use of two dimensional templates of work stations. These were either copied (under tracing paper) into a layout, or held in position by magnetic 'operators' on a magnetic table where a drawing of the industrial hall was fixed. Where the magnetic table technique was used, a photograph of the layout was taken by an overhead camera. This process was repeated after each change, introducing alternative layouts. This technique was much faster than drawing layouts with templates under tracing paper. But all the extra equipment like cameras, special overhead stands, lighting and finally engaging a qualified photographer on the job made this method expensive. Also the extra space needed and time lost by the layout engineer involved, e.g. queuing for the magnetic table and the photography, led to this method being abandoned.

The two dimensional methods had some disadvantages especially when presented to customers or non professional top management lacking knowledge of reading drawings. Also, these methods are not able to show some of the space utilisation problems. Neither are they sufficient for collision course finding among work stations and building, maintenance steel-work, columns footings (foundations), ducts, etc.. Therefore 3-D model 'templates' were introduced.

This 3-D method, deploying wooden, plastic, or metal models, is still in use for some specialised cases, e.g. piping. This, however, is a very slow and expensive method. To manufacture models of work stations and equipment, usually in 1:50 scale, is a straightforward job if wood or plastic materials are used. But storing and issuing them to layout engineers, as well as the manipulation of models of work stations within a 3-D model of an industrial hall is complicated. Plastic models of work stations, equipment, operators, etc., are usually subcontracted. For wooden models of industrial halls, maintenance steel-work, pipelines, etc., there have to be adjacent workshop facilities. This can be a very undesirable mixture of activities : design work vs. manufacture. According to good engineering practice, and ergonomic and synergetic rules (see 4.2), such activities should be kept separate.

When a 3-D model is finally built, photographs of the arrangement are taken in a similar manner to that needed for the magnetic table method.

With the development of plastic drawing sheets (Mylar) known as 'skins', a relatively very good technique, using 2-D templates fixed after manual positioning by double-sided sellotape, has been invented. This template on 'skins' technique, (see Appendix I-12), enables the engineer to change position of work stations several times to investigate alternatives. The templates of work stations are usually drawn in 1:50 scale on a thinner plastic tracing foil. The 'skins' have a pre-printed grid (250x250mm in 1:50 scale) to ease the positioning of templates. For buildings, pre-printed sellotapes, indicating walls, etc., are used.

The 'skins' are reproduced in the same way as ordinary tracing paper drawings. These 'skins' remain relatively durable. However, the dust catching residue of the sellotape creates stains. Because of their relative weight and stiffness, the 'skins' are stored hanging in purpose-designed steel cases. Overall ease of manipulation of 'skins', so similar to familiar tracing paper, makes this inexpensive method of producing 2-D layout models, sometimes called 'templates and tapes', very popular. Tompkins and White ([39-published in 1984!) stated:

> "The most common method of creating layout plans for larger facilities is to use templates and tapes."

Also Konz [58] published in 1985, described this technique in great detail.

Unfortunately none of the above discussed manual methods is fast enough, and none of them assists the layout engineer in the direction of providing economic space utilisation. They do not help in the coordination of layout tasks (system - Hall, Bay, Work Station ... Mechanical, Civil, Piping, Electrical, etc.); nor do they facilitate collision course finding.

All the layout work must currently be carried out intelligently and unaided by the layout engineer. The quality of projects therefore depends on his experience, level of education and ability to consider, assess, and foresee the technological situations in a spatial context. This also requires great engineering imagination!

The methods, described above, show how inadequate are the tools which the layout engineer is using for his highly creative and, at the same time, complicated yet repetitive assignments.

Even in a new factory situation there must be a continuous re-layout and re-arrangement activity in progress [2]. The repetitiveness of layout tasks, the need for changes of layout to be carried out in the shortest possible time, and the requirement for finding the most effective arrangement by consideration of alternative layouts, have led to the development of new methods and techniques in Factory Layout Planning.

3. COMPUTER AIDED SYSTEMS PRESENTLY AVAILABLE

3.1 INTRODUCTION

In order to avoid any duplicity of research and with the view of a possible utilisation of some of the existing computer programs for CAFLAP, an extensive literature search has been undertaken. (See Chapter 10.)

One of the sources quoted is Location and Layout Planning bibliography [48] by Domschke and Drexl, in which the authors include layout planning and any relevant systems in a wide field of "location theory".

According to them, location theory can be divided into macroeconomic and microeconomic location theories.

In macroeconomic location theories industries, economic sectors, etc., are placed 'in space'. The microeconomic location theories are further divided into plant location and plant layout theory.

Publications whose authors regard transportation cost or travel time as main location factors are described in the bibliography as transportation orientated, and of a normative (quantitative) type. This group is further divided into publications dealing with plant location and those which deal with public facility location problems.

According to Domschke and Drexler the main objective in plant location is to minimize the sum of cost (minisum problem). In public facility location the objective is to minimize the maximum distance, time, etc., which a user of a facility has to accept (minimax problem). Within both types the factor of different distances occurs. Dealing with this there are network orientated models (where the shortest distance between two points is considered - Operation Research), and models assuming that travel takes place on a plane (all points on the plane are potential locations).

Plant layout theories try to optimize the location of facilities within a building or plant, e.g. location factors are studied.

Authors have divided publications on location and layout planning into 13 chosen subjects. (The current work would fit into the class "M"-Thesis). Future trends in the development of the microeconomic location theory are predicted by the authors as mainly concerned with the development of software tools based on computer graphics. (This is the line which CAFLAP follows.)

Nugent, Vollmann and Ruml [38] are considering "the optimal specification of which facilities are to be adjacent in the final layout without regard to the area or shape of the individual facilities", as most important step in the complete layout process.

With the expansion of the use of computers, many attempts have been made to find the algorithms for the most suitable 'technological' positioning of work stations, related to each other in the sense of the most economic flow of material. Relationship charts of activity areas (based on the flow of material and service departments) have created the basis for a number of computerised methods in Factory Layout Planning.

According to Tompkins and White [39], techniques for computer aided layout may be classified by the method of recording flow among departments and by the method of generating the layout. The flow may be expressed as a quantitative record in a FROM-TO chart, or as a qualitative one recorded in an activity relationship chart.

The method of generating layout may vary from computerised algorithm developing block layout, presented by symbolically marked squares, to computer graphic presentation of detailed facilities in 3-D.

Moore in his international survey [30] in 1974 is using Wollmann's [41] classification of computer programs for facilities design as either 'construction' type or 'improvement' type. According to him the construction algorithms build or construct a solution from raw data; the improvement algorithms require a feasible solution as part of the input.

In Moore's survey eighteen programs are classified by authors as construction type, seven as improvement type, but five are not classified either way. (As Moore's classification fits better for block plan plant layout algorithms, it is less suitable for classification of other systems. If Moore's approach should be applied to CAFLAP it would fit in his class 'Others', although this class was originally created for a different purpose.)

Below are reviewed and evaluated some classical types of methods/programs from the past, which are still quoted in recent literature. Tompkins and White in 1984 [39] are actually presenting CRAFT, COFAD, PLANET, CORELAP AND ALDEP. Their selection is identical with programs chosen in Computer Aided Layout: A User's Guide [57], which quotes them as "techniques already proven to be usable to the facility designer". Konz in 1985 [58] also finds it useful to include in his book CRAFT, COFAD, CORELAP, ALDEP AND PLANET.

These classical types of program are followed by new tendencies and ways in tackling Factory Layout Planning problems.

3.2 COMPUTER AIDED SYSTEMS

Many programs and commercial software packages currently in the field are approaching plant layout as a pure operation management problem of 'sequencing' the departments or work stations, in order to receive a final block layout with shortest possible distances between the interrelated facilities. As described in the following, many of them are building on the original ideas of Armour-Buffa [5,6], Lee-Moore [8] or Apple-Deisenroth [9].

3.2.1 CRAFT

In 1962 G.C.Armour and E.S.Buffa presented their work "A Heuristic Algorithm and Simulation Approach to Relative Location of Facilities" which resulted in CRAFT (Computerised Relative Allocation of Facilities Technique - 1964), a typical improvement type program for block plan plant layout [5,6,7]. The program was developed for process (functional) layout. This method is based on the algorithm to minimise Material Handling (M.H.) costs incurred among all departments. M.H. cost is defined as the product of flow, distance, and unit distance travel cost, which are the main input data. An initial layout has to be given and must consist of a group of unit squares to represent each department. The procedure first determines the centroids of departments. Then CRAFT evaluates the given layout, calculating the rectilinear distances between the departments and stores it in a distance matrix. Then M.H. cost is calculated as product of data from FROM-TO chart (flow), distance matrix and move cost matrix.

Production departments are identified by assigned capital letters. CRAFT next considers departmental interchanges and evaluates what the effect will be if locations are interchanged. The program switches the positions of the departments to achieve, through an approximation process, maximum economy in Material Handling. M.H. costs are compared. The process continues until no more improvement can be made by pairwise exchanges. Only departments with common borders or of the same area are considered for exchanges of locations.
On final computer prints the inter-related positions of departments are marked by lines, composed of the assigned capital letters, delimiting the areas of individual departments. CRAFT program does not guarantee that the layout with lowest M.H. cost will be found unless all possible interchanges are considered.

Some assumptions made in the CRAFT algorithm could be viewed critically.Francis and White [16] commented that:
Firstly, the use of centroid locations in measuring distances, might not be realistic for some practical applications. This way some unusual layout designs could be obtained, resulting in crooked aisles.
Secondly, the asssumption that M.H.costs are significant,

known and linear in distance travelled. In the real layout this could sometimes be of small significance.

The comments on problematic assumptions are important for the user. He should see CRAFT as a conceptual tool for the design of block layout in some early stages of projects or search phase of design.

Nugent, Vollmann and Ruml in 1967 [38] compared CRAFT with newly developed similar programs H63 and HC63-66. They compared the goodness of the solutions reached and computational efficiency. The results obtained by the authors show that CRAFT runs more slowly than HC63-66; the latter produces solutions of slightly higher quality. Despite some positive results achived by programs H63 an HC63-66, none of them were quoted in literature studied and failed to appear even in Moor's survey [30].

In spite of the above criticism Francis and White in 1974 [16] finally have a word of praise for CRAFT:

> "Although there are other improvement algorithms, in general none have been shown to be superior to CRAFT in layout design."

3.2.2 COFAD

From the family of similar improvement programs, at least COFAD should be mentioned here. Developed by Tompkins and

Reed [43], COFAD -Computer Facility Design- is basically a modification of CRAFT.

COFAD allows the use of move cost for a variety of M.H. systems, i.e., each alternative layout is also considered from the point of view of the M.H. method to be selected.

Input requirements are the same as for CRAFT, expanded by the cost of M.H. system, and a percentage of utilization of M.H. equipment per move. COFAD enables the selection of the least-cost layout and in parallel the selection of M.H. method with minimal cost of M.H. equipment.

The program starts with procedures identical to CRAFT, i.e., improving the initial layout. Then the cost of each move with M.H. method alternatives is determined. Flow (FROM-TO chart data) is constant. Next comes determination of a minimal cost M.H. system which is followed by a search for M.H. equipment whose utilization is good.

In the next phase reduction in total cost is sought. If in the COFAD process no reduction of total cost can be achieved, the program is terminated or flow volume inputs are changed. This is done for following reasons: to confirm that the found solution is a steady-state solution, and to check the sensitivity of design to the flow data. If the steady-state is not confirmed, COFAD is restarted with a new apportioning of cost of M.H. system to individual moves. This loop continues until the requested (steady-state) solution is obtained.

The assumptions inherited from CRAFT (as discussed above in this connection) are inevitably sources of the same critical comments. Here the situation is made even more complicated by the variety of M.H. methods considered, and their costs due to the variation of market prices. Another complication arises in connection with the collection of data regarding the realistic percentage of utilization of equipment, which is always difficult to establish.

Further programs of a similar type in the improvement class quoted by Moore [30] are: GRASP, KONUVER, LAYADAPT, OFFICE, PREP and The Terminal Sampling Procedure. In 1978 Tompkins and Moore [57] are adding to this list another two: COSFAD and SET.

3.2.3 CORELAP

As a classical example of construction type program [30] could be seen the digital computer program CORELAP [8]. CORELAP-Computarised Relationship Layout Planning- was developed by R.C.Lee and J.M.Moore in 1967 to design block plan plant layout economically. It is a job shop orientated procedure.

In comparison with CRAFT, which is using flow consideration for it's procedures, CORELAP procedures are based on activity relationships (originally suggested by Apple[10]). Activity relationship (REL) charts are using A, E, I, O, U, X, rating convention [4, 10].

For input the following data are required:

- the number of departments (N)
- the data from REL chart
- the area requirements for each of the departments
- the ratio of maximum length of the building to width.

The heuristic algorithm starts with areas having the greatest sum of relationships. The departments with the highest total closeness rating (TCR) is placed in the centre of layout matrix. The program then interactively adds other areas, one at a time, in such a way as to maximize the attainment of the desired relationship. The final output is in the form of layout matrix. On the print of the final layout, whole areas of departments appear covered by identifying numbers, each representing the unit square it occupies. The areas which are available but not occupied are marked up by zeros. Layouts designed by CORELAP are often of an irregular shape. To fit a conventional shape of a building, this has to be adjusted manually.

Similarly to CRAFT, CORELAP should be considered as a conceptual tool for the design of block layout in some early project stages or research phase of design.

3.2.4 PLANET

Another construction type program often quoted in literature is PLANET - Plant Layout Analysis and Evaluation Technique-developed by J.M.Apple and M.P.Deisenroth in 1972 [9,7,39]. PLANET was also developed for design of block layout.

For input the following data are required:
- material flow data (i.e.entries from the FROM-TO chart)
- move cost matrix
- distance matrix

PLANET uses three alternative methods for specifying material flow data. In the design procedure three different layout construction algorithms are used.

The three methods of specifying material flow data are following:

The first one specifies product sequence by department for each part, together with cost per move per unit of distance for each part. The cost is often input as unity, because it may not be determined. PLANET then develops a flow-between cost chart, which indicates the cost of movement between pairs of departments. This is then used in the construction algorithm.

The second method inputs material data directly from FROM-TO chart, which is then converted to a flow-between cost chart.

The third method of inputting flow data is that using a penalty matrix. The penalty input between two departments is an indicator of the importance of closeness of the departments. The matrix can also indicate the difficulty and relative frequency of material movements between departments, or indicate the relationship data. A placement priority scale 1 to 9 is used (9 is the lowest priority). The layout is not predetermined.

The three construction algorithms used in PLANET are best described as follows:

Method A selects departments according to flow-between costs, starting with pairs of highest priority group with the highest flow-between costs. The next department to be selected is that from the highest priority group and with the highest flow-between cost with any department already placed. In this fashion the procedure continues until there is no department left unplaced within the layout.

Method B starts in a similar way to that of A, but the next department to enter is chosen from the highest priority group and has the highest sum of flow-between costs with all selected departments. This continues until no department is left unpositioned.

Method C starts with the department in the highest priority group that has the highest sum of flow-between cost with all other departments. As the next entry, method C selects the department in the highest priority group that has the highest sum of flow-between cost among all other departments. The procedure continues until no department is left unpositioned.

The layout routine always starts with the two top selected departments placed in the centre of the layout. Any following department is placed in a manner which will minimize the M.H.cost, using a trial-and-error method.

PLANET often generates layouts that do not suit a uniform building shape, so deficiencies are similar to those of CORELAP. Layout must be manually adjusted but this cannot be evaluated by PLANET as feedback. PLANET can be considered as another conceptual technique for initial stages of projects or search phase of design.

3.2.5 ALDEP

ALDEP -automated layout design program- was presented by Seehof and Evans in 1967 [54]. As classified by Tompkins and Moore [57] this is another construction type routine.

First the authors studied the attributes which condition a better layout. They suggested a scoring technique, and used a matrix of weighting factors which indicated a desirable closeness of departments. The layout score is the summation of the preference values for the adjacent departments. No details of preference values (factors), or scoring techniques have been published by the authors. However, Tompkins and Moore [57] used in their assessment of ALDEP Muther's [4] A,E,I,O,U,X relationship rating.

The main input data are:

- number of departments and their square footage,
- relative departments location preference,
- layout of the building (building dimensions, etc).

ALDEP creates a random layout and scores it. This is repeated several thousand times to reach the best scores. Compared with CORELAP, ALDEP produces many layouts and rates them leaving the selection of the best alternative to the user; while CORELAP attempts to produce one best layout. Block layouts are produced by a plotter. Selection and adjustments for the final layout are done manually. ALDEP can be only used for block plan layouts with predetermined aisles, stairs and other amenities. ALDEP cannot be utilised for a detailed layout or 'technological' positioning of work stations, and therefore cannot be used as an entry programme for CAFLAP.

It is worth quoting that, in 1979, Rosenblatt suggested a new algorithm [60] which, as he claims, could be used with

ALDEP. He uses a combined quantitative and qualitative (subjective) approach to the plant layout problem. His supposition is that quantitative and qualitative approaches are formulated as a quadratic assignment problem. Both have the same feasible region, therefore the two methods can be combined. His multi-objective formulation, minimizing total flow cost and maximizing total closeness rating, is made possible by the introduction of weight assigned to the total cost flow and total rating score. Rosenblatt suggests a graphical solution to find the 'best' layout. The 'best' layout lies on the intersection of a line, established by the weights, with a point on a 'discrete efficient frontier', given by positions of efficient layouts in the graph.

Moore in 1974 [30] quotes in this class of programs (using construction algorithms) another 16 programs. They are: CASS, COLO2, COMP2, COMSBUL, DOMINO, GENOPT, IMAGE, KONUVER, LAYADAPT, LAYOPT, LSP, MUSTLAP2, PLAN, SISTLAP AND ṢUMI. In 1978 Tompkins and Moore [57] added another two: Hiller-Conners and RMA Compl.

A number of further programs based on the above mentioned classical types have been developed. Some authors tried to eliminate the disadvantages mentioned above, some tried to develop the system in a more universal way or to extend their use into other areas.

Examples of the latter intentions are MODULAP and SPACECRAFT.

3.2.6 MODULAP

Real situations, influenced for example by transport routes, were not considered previously. The development of new more practical methods was then begun, e.g. MODULAP [11].

MODULAP, contrary to CRAFT or CORELAP, measures the real distances alongside the transport routes. However, it still cannot guarantee the positioning of all the departments along the transport routes, and the layout engineer has to define the required additional routes intelligently. MODULAP first designs an ideal layout and then, in a second round, converts the ideal layout into a feasible alternative. Similarly as all the above quoted methods, MODULAP is also more suitable for block layout and the positioning of departments, rather than for the more detailed positioning of work stations.

3.2.7 SPACECRAFT

SPACECRAFT was developed in 1982 by Roger V. Johnson [44]. It is a construction type program based partly on CRAFT method. Johnson is trying to minimize the total variable cost of movements (M.H.) between facilities in multi-floor buildings.

The aim of the program is to locate the departmnets in a feasible way, and the total time of journeys on N floors is minimized. Johnson consideres the volume or number of journeys from department 'i' to department 'j' as constant, but the time of a journey will depend on the location of departments 'i' and 'j'. The main difference between the multi-floor problem and the single-floor problem is, according to him, the nonlinearity of transportation times.

For input, SPACECRAFT requires:
- building size data (number of floors, number of floor types, number of columns, rows of modules and definition of floor types),
- travel times between each pair of floors, for each inter-floor access route,
- travel times between each pair of modules within each floor type,
- travel times between each module on a particular floor type and each access point,
- department information (number of departmets, a code number of departments, department titles, volume of movements between each pair of departments),
- Initial layout and its restrictions and any requirements, or restrictions of any department.

SPACECRAFT, in a procedure very similar to CRAFT but with the difference caused by the nonlinearity of transportation times between floors, produces:

- table of movement times between each pair of floors,
- table of movement times between each pair of modules on each floor type,
- table of movement times between each module and each vertical movement point on each floor type,
- table of volume of movement per period between each pair of departments,
- table of single journey movement times between each pair of departments,
- table of single journey movement times between each pair of departments which have a nonzero volume of movements,
- table of the dollar cost of a single journey between each pair of departments which have a nonzero volume of movements,
- table of total per period movement time between each pair of departments,
- table of dollar cost of the total per period movement time between each pair of departments,
- summary of total per period time and cost of movements originating from each deparment,
- location data listed for each department,
- location data listed for each floor,
- layout grid of the building.

The graphical presentation of layout designed by SPACECRAFT is similar to that of CRAFT. But the positions of departments are indicated by symbolic numbers instead of the letters used for CRAFT. The numbers are printed in a grid given by column numbers, module row numbers, and floor numbers. This grid feature could be seen as an improvement on CRAFT and the method can, similarly to CRAFT, be used for the development of block layouts. However, SPACECRAFT cannot guarantee an optimal solution. A poor layout will result in higher utilization of elevators.

This method was commented upon by Jacobs in 1984 [45]. He compares SPACECRAFT to a program known as CRAFT-3D developed already in 1975 [46]. Jacobs considers the programs as very similar, with the following difference. SPACECRAFT considers all the travelling distances parallel to the department edge, not diagonally, while CRAFT-3D calculates with rectilinear distances measured between department centroids.

In spite of their discussion of space and 3-D programs, SPACECRAFT and CRAFT-3D are both actually only solving 2-D layouts on different floor levels.

In comparison with CAFLAP (see Chapter 4.) they are actually only 2-D and symbolic in presentation. They also have no facility for 'space management', automatic positioning in 3-D space with collision course finding, etc.. This comment is also true for CRAFT, COFAD, CORELAP, PLANET and MODULAP programs.

3.2.8 SHAPE

SHAPE -Selection of material handling equipment and area placement evaluation- program [47], was presented by Hassan, Hogg and Smith in 1986. The aims of Shape resemble those of CORELAP (3.2.3) or PLANET (3.2.4). The intention was to develop a functional layout with minimum interdepartmental movement costs. SHAPE tried to find the 'best arrangement and configuration of departments' [47]. This was considered in terms of a real area shape.

SHAPE used warehousing methods for locating a new single item in existing stores. This was a new approach to plant layout design. SHAPE divides the layout into a mesh consisting of numbered unit squares (1 to N). Constraints are:

-Departments (n) are occupying a number (compact collection) of unit squares (Ai),

-Each unit square in the mesh is to be occupied by only one department.

SHAPE allocates the unit squares for each department and tries to minimize interdepartmental movement costs. In a similar way to CRAFT and PLANET, SHAPE uses a quantitative departmental relationship (FROM-TO chart), with the difference that each flow value is classified as major or minor and is defined by the user. SHAPE determines the order in which departments enter the layout according to the sum of the major flow values. The first selected department is placed in the centre of mesh. The rest of departmnets are placed around according to their flow values. Departments with the largest flow values are near the centre; those with decreasing values are placed in the direction towards the perimeter.

Similarly to CRAFT, centroids of departments are established and the rectilinear distances between the centroids are used. The movement cost here is the product of average distance and flow between placed departments. The placement procedure is similar to PLANET and is extended by a process orientating departments in the layout according to the minimum movement cost. The process allows the shape of departments to be changed by influencing objective functions of the model; i.e. the flow-distance product controls the selection of unit squares and therefore changes the shape of the departments. In the final layout every department is of an optimum shape, while the least movement costs between departments are secured.

In spite of the authors' original claim about SHAPE dealing with "selection of material handling equipment..." no selection is discused in the paper presented [47]. SHAPE is also compared in the paper with PLANET and CRAFT, but if selection of M.H. equipment is considered it should rather be compared with COFAD (3.2.2). The comparison with PLANET, provided by authors in detail, shows SHAPE's advantage of up to 23% reduction in movement cost.

The final layout is presented as a 2-D layout matrix of unit squares. Each unit square represents a particular area of the department, coded by a number. Thus SHAPE can be used, similarly to the previously described programs, as a conceptual technique for the initial stages of project or search phase of design.

Unlike CAFLAP and in company with the other programs dicussed here it also has no facility for 3-D presentation, no facility for detailed layout or collision course finding, etc.. Because of its otherwise unique ability of changing the layout shape it can be used for block layout, but is not suitable for 'technological' positioning of individual work stations and therefore cannot be used as an entry program for CAFLAP.

The disadvantages of SHAPE for practical layout are similar to CORELAP, PLANET and CRAFT. Unusual layout designs can sometimes be generated by SHAPE and the resulting crooked aisles cause difficulties in practical M.H. Moreover, placement of the work stations in the detailed layout may prove to be difficult, if not impossible, because of the changed shape of departments.

SHAPE should be seen as a most recent attempt to improve the existing line of heuristic construction algorithms based on the classic ideas of Lee and Moore in the sixties.

3.2.9 RUGR

In parallel with the construction and improvement types of programs, Moore introduced, in his survey [30], another class of programs: graph theory [50]. A classical representative of these types of program is RUGR, already presented by Krejcirik in 1969 [12]. Using the graph theory Krejcirik tried to consider the plant layout problems within the limits of an existing building and given areas. His RU-Program is designed for finding the optimum arrangement of spaces which lie alongside a corridor. He was partly inspired by Armour-Buffa's CRAFT program but, contrary to this program, his arrangement of spaces (e.g.departments) follows a direct line, distributing them evenly within the building, without any waste of space available.

Krejcirik's RG-Program is intended to find mutually related locations of spaces on one plane, while the RR-Program is designed for the minimization of total area of the layout, in order to achieve the most economic size of the building. RUGR is suitable for 2-D plant layout block plans.

Seppänen and Moore in 1975 [53] reviewed the graph theory. They found that it is not always possible to represent the plant layout situation as a planar graph. String processing algorithms, using Novelty Luggage problem method, were suggested as an alternative approach. But this method has not been further developed and implemented using a computer.

3.2.10 MATHANDL

Very important techniques for the 'technological' positioning of work stations have been developed by the University of Strathclyde.

Program MATHANDL [13] introduces a new technique of arranging work stations into lines instead of clusters, as it is in CRAFT and CORELAP, and removes the shop foor limitations which are inherent in these methods. To achieve this, Numerical Taxonomy, a computerised approach to biological classification has been adopted to develop a computerised algorithm. However, the developed program is at present not available for multiple machine departments. The method of numerical taxonomy was further studied by Carrie [51]. He also observed [55] that the technique of numerical taxonomy provided an analytical procedure similar to the intuitive one of the plant layout engineer. For the Layout of Multi-Product Lines [14], he has proposed a computer method of preparing alternative line layout designs. The method considers work flow and work load and proposes a three stage procedure:

1) Construction of a 'complex' line which contains enough work stations at appropriate positions to allow every part to be processed without back-tracking;

2) Identification of those machines which do not have an economic work load, and eliminate them by re-routing the operations planned to be performed on them to other machines in the line. This is done in an interactive manner producing several possible designs;

3) Comparison of the alternative designs by computer simulation.

The simulation model was written using the GPSS package [26].

3.2.11 PLANTAPT

PLANTAPT - a prototype integrated package for layout planning analysis- was presented by Carrie in 1977 [54]. This general purpose package is intended for medium size plant layout and group technology applications. PLANTAPT's file system holds following data:

- for a number of independent projects,
- on component parts,
- on plant resources, machines or processes;

it is designed to:

- permit variations in the data,
- permit max. flexibility in the data layout in input documents,
- store and retrieve results of application programs.

PLANTAPT's application programs are designed for:

- specifying the component parts to be examined,
- specifying the machines to be considered in the analysis,
- analysing group technology code numbers (Opitz),
- analysing the operations carried out on parts,
- developing the layout of group flow lines and rationalising operation sequences,
- analysing material flow or activity relationships for planning overall layout or detailed layout.

PLANTAPT programs first analyse the situation and then, in a grouping operation, design parts groups, and corresponding groups of machines. If no grouping is necessary, each item becomes a group of one. A facility for operation sequences is provided. If a multiple-product flow line is being considered, machines for the flow line are selected by a specialised program.

Integral parts of PLANTAPT are programs called TRAVEL and LAYOUT. TRAVEL computerises relationship data, while LAYOUT develops a maximal planar subgraph (the theoretical ideal layout) from which a practical plant layout can be designed.

A graphical extension of PLANTAPT was described by Carrie in 1980 [55]. He used PLANTEC, an interactive package for plant layout, developed by National Engineering Laboratory [56]. PLANTEC stores and supplies 2-D shapes of buildings and machine templates. Coordinates of the shapes, relative to a convenient origin, are measured and filed. This can also be done by digitising the shapes. Similarly, positions of machines in the layout are given by coordinates and scale factors can be given. The layout is presented on VDU and manually adjusted according to engineer's discretion. When the layout reflects the theoretical ideal layout best, the engineer can instruct the computer to provide a large size plot of the layout drawing.

Utilisation of Strathclyde's techniques MATHANDL and PLANTAPT is suggested for the benefit of CAFLAP (section 4.3).

3.2.12 A large-scale spatial allocation problem

A large-scale spatial allocation problem was formulated in 1980 by Liggett [61]. He used a quadratic assignment approach combined with a 'partitioning scheme'. This very interesting method allows the efficient solution of layout problems, positioning up to 1000 departments, shortening the computing time substantionally. The 'partitioning' approach solves a layout at a set of nested levels. The highest level (master partitioning problem) assigns activity modules to subsets of locations. These are grouped into zones or 'partitions'. The method used for selecting the assignments in levels considers the immediate costs of assignments (activities to locations) and the restrictions imposed on possible choices for future assignements. Probability theory is used to predict which assignment would most likely lead to an optimum solution, and therefore which is the most suitable as a possible future choice.

This partitioning method is said to be very effecive and computer time saving. It is appropriate for architectural space allocation but unfortunately it leads to irregular shapes of departments, and on a much higher scale than in CRAFT (which is the program used by Liggett for comparison). The method is therefore much less suitable for mechanical engineering application.

3.2.13 INLAYT, S-ZAKY (an interactive approach)

An interactive approach to construction and improvement procedures was described by O'Brien and Barr in 1980 [34]. They tried to overcome some problems which are inherent in the above quoted procedures, by introducing the user's participation in the selection process. Program INLAYT is designed for the construction of initial layout for a new factory, or improvements in an existing one. The improvement procedure, based on program S-ZAKY, is asking the user to evaluate the 2-D layout on VDU.

INLAYT analyses the flow of material between facilities and suggests to the user groups of facilities and priorities to select for positioning. The user then has to position the facilities in the layout manually. The procedure disregards the actual areas required, and is concerned with relative location only. INLAYT does not produce the final layout, it only provides the initial input to the improvement procedure S-ZAKY.

Input data into program INLAYT are following:
-The number of facilities,their names and indentification numbers.
-The spatial array of building or site.
-The weighted flow of material between facilities.
-A flow factor (a control variable specified by the user).

The order of departments is produced by the program and stored in a matrix organised according to maximum values of weighted flows. Facilities are assigned to a space location grid by the light pen.

The improvement procedure S-ZAKY must start from an initial layout. This can be produced by INLAYT, or the existing layout or any other proposal can be used.

Input data required:
-The name of each facility.
-The area of each facility.
-The relative location of all facilities.
-Details of fixed facilities.
-The coordinate positions of all machinary.
-The coordinate position of material set-down and pick-up.
-The orientation of set-down and pick-up with each facility.

-Estimates of cost of relocating each facility.

-The cost of investment capital.

-The lifespan of the programme being considered.

-Control variables.

The authors claim that the improvement algorithm S-ZAKY is superior to other avilable algorithms. The main reason is that they interchange three pairs of facilities instead of two, as CRAFT and other programs do.

The 2-D layout is presented on the screen together with the total M.H. cost. Material flow pattern between set-down and pick-up can be superimposed on the layout. Series of questions are asked regarding further procedures required. In the case of exchanging facilities the program will reposition aisles. The rearrangement of facilities is left to the experience of the user, who can move facilities (2-D templates) manually by the light pen. The improvement layout is assessed by computer. The procedure continues until no more improvement can be achieved. Total M.H. cost which is the prime factor in this procedure is compared with the cost of physical repositioning of facilities. The ratio of these costs indicates the economy achieved by the changes. If no requested economic effect is achieved, the relayout procedures could be resumed and the process is repeated. The procedure can handle up to 100 facilities but all areas must be rectangular, and the system of aisles must be rectilinear, which is a substantial limintation.

The INLAYT-S-ZAKY method has certainly brought a new approach to factory layout planning. Unfortunately there does not seem to be any independent assessment of the method yet published. There are also limitations similar to other comparable methods e.g. the inaccuracy of the input data on M.H. cost, installation costs, etc..

Kaltnekar in 1980 [62] considers three groups of criteria for layout decision making: limiting, mutually influencing, and marginal conditions. These criteria dictate approaches and Kaltnekar reminds the reader that most of the literature mainly considers the relationship between layout and material flow while other factors are ignored. To balance this he suggests it appropriate to study the above three groups of criteria:

Limiting conditions are those which cannot be changed (i.e. market,sources,etc.).

Mutually influencing conditions are those which can be changed (i.e. M.H., flexibility of layout, outside transport, building construction, conditions for the employees, the mutual influence of different parts of production system, etc.).

Marginal conditions are all conditions surrounding the production system (i.e. the social order, disposable workforce, financial posibilities etc.).

Because of the large number of different influencing factors, the criterion of minimization of particular functions or their costs is used. Kaltnekar's critical observation that every method offered optimizes a model, and not the real state, is a crucial one. His improving algorithm only emphasizes that the result is still far from a satisfactory solution.

Prof. Lockyer [21] in 1981, when assessing the existing computer aided layout planning systems, is quoted as saying that:

> "...computer programs may assist the planning function by avoiding an oversight and this is a common experience when using computers, in that the preparation of input data enforces a discipline which is often useful. It is the author's experience that layouts are currently, in fact, prepared entirely manually, and his belief that the use of the computer in this area will, for many years, be extremly limited."

In this rather unsatisfactory situation, new attempts to ease the layout engineer's work were made, especially in the area of simulation and systems using computer graphics.

3.2.14 SEE WHY (FORSIGHT)

In 1984 B.H. Hollocks [25] suggested a new approach to plant layout problems through computer simulation. His program FORSSIGHT experiments on 'real world' layout situations. The engineer may change the layout situations and the program finds out the influences of the options, before any decisions (changes, purchase of equipment etc.) are made.

The method was originally developed at British Steel for reflecting a course of activity on physical mimic displays. The computer simulation run was valuable for giving a fuller understanding of the behaviour of mimic displays in specific circumstances. It is claimed [25] that the FORSSIGHT program "enables an accurate computer model of real world production plant to be constructed quickly and easily". It gives production statistical results and can produce an animated view of the model in operation. FORSSIGHT also enables the user to change operating parameters and to observe the results. Departments or work stations are presented as 2-D blocks (as is usual in mimic diagrams), but without any real shop floor area or space considerations. FORSSIGHT has recently been renamed SEE WHY: it is a good package for the study of cost effective production flow.

3.2.15 UA1, UA2, UA3

From the range of other simulation programs it is worth mentioning programs presented by Driscoll and Sayers in 1985 [68]. The authors have studied a dynamic facility relayout, and developed three new programs:

Program UA1 undertakes data validation. For static layout design program UA2 is used, while UA3 is designed for changeover simulation. The programs have the facility for evaluating alternatives on a financial basis.

Static 2-D layout (in UA2) is determined by coordinates of the building outline; facilities are represented by rectangular or circular shapes/areas. Facilities (workcentres) are grouped into sets and the placement of facilities is done manually. The relayout starts with the existing layout, the new arrangement, and with the support of M.H. information. The changeover simulation model (UA3) operates subject to a number of assumptions which define the changeover situation, e.g.: specified life-span, times of relocation, limits on the number of relocated workcentres, limits on relocation moves (within a period), etc.. There are three types of changeover:

-instant changeover (at time zero)

-slow changeover (with intermediate layouts)

-changeover while stopping production for early benefit from the new layout.

UA3 evaluates the changeover, on the basis of M.H. costs and workcentres relocation costs. M.H. distances are calculated as straight-lines, where no traffic routes exist, or as the shortest distances around the traffic system. In comparison with CRAFT and PLANET, UA3 considers not only the cost of journeys but also extra costs i.e. M.H. fixed costs, consisting of pick-up and set-down costs. A priority rating expressing the order of potential gain from changeover is used. Program UA3 prints details of M.H. costs troughout the simulation.

The authors are fully aware of the vulnerability of M.H. criteria if considered in isolation. The dynamic facility layout draws a comparison between M.H. cost and the rate of profit from production in the new changover situation on, on the one hand, and the cost of the relocation of facilities, on the other hand: this produces a better picture of the changeover.

The simulation model is designed as an aid for decision making regarding changes of layout, rather than as a tool for actual detailed workshop layout.

In the class of major and expensive simulation packages programs MAP and CDAS were introduced.

3.2.16 MAP

MAP -Manufacturing Automation Protokol, was developed by General Motors in cooperation with Boeing, and introduced in 1986 by Baer [69]. The system is able to handle 3-D CAD data, NC tool paths, robots, automatic quided vehicle instructions and shop traffic instructions. The MAP package can be integrated with CAD/CAM system. According to Baer, the MAP system is very expensive and currently beyond the means of medium and small-sized companies. MAP enables communication and control of the shop floor. Operations in this particular application include loading, cleaning, soldering and stacking. Using MEDUSA CADD software, the system was used to draw the cell configuration, but the levels of manual/automatic drawing or any specialised factory layout facilities are not documented.

MAP is clearly orientated as a large scale process control system, including MRPII (material requisitioning) programs. Therefore any comparison with CAFLAP, which is a special purpose, plant layout orientated system, can hardly be made.

3.2.17 CDAS

Immediately after MAP, Rockwell's Configuration Design Analysis and Simulation Environment System (CDAS) was introduced by Tice [70]. It was primarily designed for the simulation of future human or robotic on-orbit servicing procedures during space flight. Low fidelity computer graphic visual simulation was used. All positions and motions of objects were calculated ahead of time and could be recalled in 3-D presentation, frame by frame. Tice claims that CDAS can be used for:

-designing spacecraft, tool and cradle hardware,

-analyzing remote manipulator system

-checking effectivenes and feasibility of design

-simulating design, redesign, feasibility and efficiency operations.

At the present time, CDAS has no collision detector.

Grant and Weiner [71] evaluated ten Animated Simulation Systems in worldwide use. This included the "See Why" system already described in paragraph 3.2.14. The systems evaluated were:

AutoGram, BEAM, Cinema, Modelmaster, PCmodel, RTCS, See Why, SimFactory, Simple 1 and TESS.

The features compared are:

-simulation model building system

-animation graphics

-operational consideration

The model building system is most important both for the model builder and for the user. Five of the above systems are special purpose with manufacturing orientation and five are general purpose systems. All but one system uses use two dimensional animation graphics. Only AutoGram uses 3-D and the graphics display allows observation of the designed system from different perspectives. AutoGram allows the creation of layout from drawings, via a digitiser. The other systems offer mouse driven menus of characters or shapes.

The listing of these features reveals that none of the simulation systems are similar to CAFLAP.

The Buyer's Guide to CAD systems [72] was studied and it shows that although different CAD system offer various and sometimes very sophisticated facilities, none of them is similar in operation or presentation to CAFLAP (see also Chapter 4.2.).

3.2.18 GRASP

Another interesting package recently developed is GRASP [29]. This is a practical tool for the visualisation and study of relative positions of work stations with respect to robotics and movements of parts in 3-D Computer graphics. GRASP was designed predominantly for:

1) Programming robots;

2) Process purposes (showing what the robot is doing and finding movement paths. A Clash detector menu can indicate, by flashing, the clash of parts or equipment);

3) Robot purchase.

The system is orientated on Flexible Manufacturing Systems (FMS) and on relatively small areas or spaces of manufacturing cells. At present it has no facility for labelling the work stations with tag numbers and dimensions, although this may be a feature of a new program GRASP 6.1 which is now being developed. GRASP is certainly a very powerful system and could in future be expanded into other specific areas.

Parallel to the above mentioned new approaches, research still continues in the field of 'technological' positioning of facilities (considering mainly flow factors and desirability rating). This can be seen documented by the works of Foulds, Giffin and Cameron in 1984 [63, 64 and 65] and Foulds, Giffin and Evans in 1985 [66].

The last word in block layout design is apparently the study of Evans, Wilhelm and Karwowski [31] presented in 1987. Instead of the previously mentioned techniques, they suggest the use of the theory of fuzzy sets. The authors consider flow rates and REL charts as vague concepts, yet the inexact data could be handled with the use of fuzzy methodology in a mathematically strict way.

However, Herroelen and Van Gils, in 1985 [67], in a similar manner to Kaltnekar [62], critically examined the main stream of research following the ideas of flow dominance. Assessing the stream of studies following the concept of CRAFT, they come to the following conclusion:

"Using flow complexity measures to decide on the particular layout configuration to be installed ... is a mere neglect of the many complexities involved in designing a plant layout and materials handling system..."

"...the layout complexity issue is in desperate need of further research..."

All the above references show methodical differences in approach to solving layout problems and a genuine effort to find a way of facilitating the industrial/layout engineer's work. Despite all this effort, Lockyer's claim [21] that the layouts still have to be designed entirely manually, persists. The Writer believes that this failure to find a better method was not only caused by the fact that in Factory Layout Planning "there are a number, and sometimes conflicting requirements" (as claimed by Lockyer [3]) or by methodology of approach, but also by the state of computer science. As in many other engineering fields, it is the recent development of the techniques in computer graphics that is generally opening new horizons. In this particular work it is these techniques which have made CAFLAP possible!

4. COMPUTER AIDED FACTORY LAYOUT PLANNING

4.1 ENUNCIATION OF THE PROBLEM

Factory Layout Planning "is at best an imprecise craft" and "layout planning never developed into a clear procedure" stated Muther ([57-Preface], [4]). Nugent [38] and others see its combinatorial nature. "Factors influencing layout are numerous" says Kaltnekar [62]. Order, product, production programme, production planning, production, manufacturing systems, cost of product, and capital investment are just the main factors influencing Factory Layout Planning (Fig.2.) to be quoted.

Only with all the digested knowledge of what Factory Layout Planning involves (see Chapter 1,2 and 3) is it possible to select the area of layout planning which is suitable for methodological improvements with the use of computers. Hence the area of space demands and space relationship has been selected as the main topic for this Thesis. Contrary to all the above mentioned packages, CAFLAP solves SPACE RELATIONSHIP AND SPACE REQUIREMNT problems.

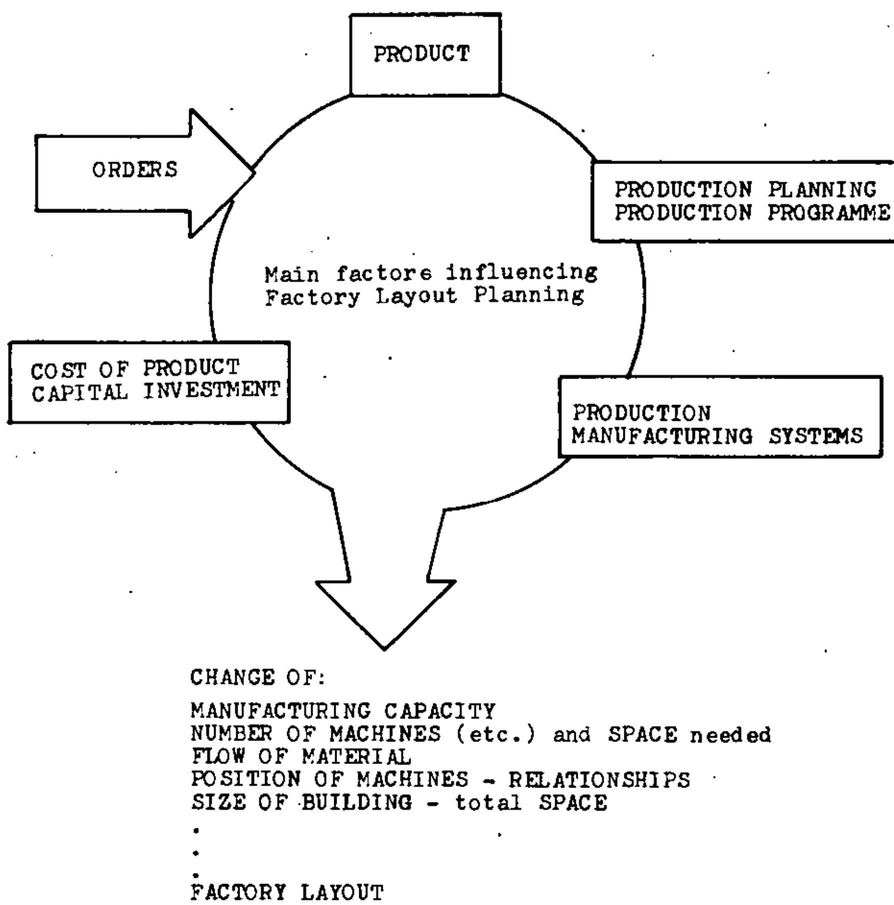


Fig. 2. MAIN FACTORS INFLUENCING FACTORY LAYOUT PLANNING

CAFLAP consideres the relative positions of 'spaces' (Manufacturing Space, Product Space...see section 4.2) conditioned by the technological requirements and demands of optimum utilisation of building space (Civil Engineering Space).

To fulfil the task, the following particular areas and steps are considered:

a) Manufacturing, as a system, is re-defined for the purpose of Computer Aided Factory Layout Planning in dynamic and spatial terms.

b) The definition of a Work Station Module as a new 3-D 'template' for the use in computer graphics is established. (A Specimen of a Work Station Card which can also be used for the purposes of a complete computer aided Production/ Industrial/Project Engineering control and planning system, is developed.) Material Handling studies, regarding space and its 'filling' are pursued.

c) A specific computer graphics system, PICASO (see section 4.4), is selected.

d) The principle of a 'continuous industrial bay' and 'Product Space Zone', as an aid for layout planning, is defined.

e) Programs for the design of individual Work Station Modules, Buildings, and for Manual Positioning of Work Station Modules are written.

f) A program for the manipulation of the whole scene to allow the user to observe the layout from a required position is written.

g) The development of the system into an automatic positioning system, considering mainly the interdependence/interaction of spaces, is contemplated: programs using a combination of automatic and manual positioning are developed.

h) The criteria for the automatic collision course finding of work stations with building elements are established.

The end product is an automated tool, assisting engineers to design/optimise the layout, in terms of most economic space utilisation, while maintaining 'technological' positioning.

Alongside the main layout problems it was also found essential to consider:

- Production Management conditions (see 4.2).

- Material Handling problems influencing the Layout and the size of the Industrial Bay (see 4.2).

- Retrieving work stations for a suggested production line from a chronological list. This happens after the 'technological' position of work station has been determined.

- Capacity calculation for Feasibility Study and Investment Project (e.g. number of work stations needed etc.).

The CAFLAP system was originally aimed at layout and re-layout of a medium-size engineering company with batch type production and with a maximum product weight 60kN.

4.2 SYSTEM MANUFACTURING

In the last decade manufacturing has ceased to be observed as a pure mechanical technology problem. The increase in overall production output is no longer considered to be purely a matter of the introduction of more advanced machining or other technological methods. Studies of machine break-down, for example, have led to a new approach to maintenance. Similarly, concern about the human factor failure in fulfilling the requested tasks accurately and in the shortest possible time and consequently, studies of the relationship between workers and their environment, have brought about the development of a new discipline: i.e. Human Factor Engineering, or Ergonomics. Attempts to optimise the operator's output have resulted in the development of the subject of Synergetics.

Maintenance:

To avoid excessive wear and tear and break-down of machines a system of 'Planned Maintenance' has been developed. The principles of planned or preventive maintenance have been known for many years, but were formulated methodically in the sixties in the studies of the Ministry of Technology [73]. Since then the interest in Planned Maintenance has been growing steadily: the works of Clifton [74], Heintzelman [75] and Patton [76] are of note.

Planned Maintenance creates conditions for diminishing the losses resulting from machines down-time. In an attempt to minimise the maintenance demands and costs, a new discipline in machnine design, 'Design for Maintenance', has been developed.

Planned Maintenance is defined as an activity including all necessary works on, and services of, work stations (machines), organised in pre-planned time cycles, to maintain them in good working order.

Maintenance requirements are also described in many factory management books e.g. Lockyer's 'Factory and Production Management' [21]. It should be said that maintenance practice and maintenance cycles vary from industry to industry, and with the type of machinery installed. However, there is an underlying general pattern of planned cycles of improvement and of preventive and corrective maintenance, as formulated by Patton [76].

Larger time scale cycles (years) usually contain provision for:

- Preventive Maintenance (Appendix I-9) (greasing, cleaning, adjusting, repairs taking less than 3 hours, etc.);
- Major Overhaul (complete inspection, parts replacement, renovations);
- Safety Inspections (elimination of safety hazards);
- Modification and Modernisation (alteration of present machines for more demanding functions, e.g. gearing); and
- Emergency Repairs to keep equipment operative (taking more than 3 hours).

From the above mentioned types of maintenance services, Preventive Maintenance is the most important for CAFLAP. It is itself organised within smaller cycles (day or week):

during shifts - oiling, greasing, adjusing;
between shifts - inspection, adjusting, oiling;
during night shift (24 hrs interval) - cleaning, small repairs taking less than 3 hrs, etc.

As the services are performed in the area of the work station, they create demands on Maintenance Space. In the past, when importance of Planned Maintenance was not widely recognised, the space needed for maintenance was often overlooked or neglected at the design stage. Losses resulting from this were evident. It is important to note that in the CAFLAP system developed here, the provision for Maintenance Space is embodied.

Design for Maintenance means giving the necessary support to all the functions of the machine. For example, an easy access to all oiling, greasing and inspection points must be guaranteed. Assembly procedures/provisions should serve easy replacement of parts and for all other maintenance purposes. Energy supply lines (pipes, cables), should be designed in such a way as to avoid crossing problems during maintenance. Lubrication and cooling should always be on the opposite side of the operator's post. Where possible, maintenance free material (e.g.plastic, sintered bronzes) should be used. Swarfing (cleaning of machine tools from all scrap of machining process) should be designed for most ease of removal [22].

Both Design for Maintenace and Planned Maintenance are determining factors influencing the demands on space around any work station. This, denoted in CAFLAP as MAINTENANCE SPACE, is further discussed in paragraph 4.2.1.1 and 4.5.1.

Human Factor Engineering - Ergonomics:

Human Factor Engineering is a branch of technology that helps to design machines, operations, and environment to match human ability and limitations. Human Factor Engineering is a term used mainly in the USA [82].

The term Ergonomics is used mainly in Europe [21,81] and the definition is slightly different from that of Human Factor Engineering. Ergonomics is seen as scientific study of the relationships between man and his work environment. The first studies in what is now called Ergonomics, started as early as in World War Two. Explanations were sought as to why bombs and bullets often missed their targets, planes crashed and friendly ships were sunk without apparent reason: it was discovered that a human factor had frequently to be blamed. After the war research continued in manufacturing industry where the reasons for a high percentage of faulty products were studied.

Again the human factor was found responsible. The main sources of problems were:

Monotony of work (especially on assembly lines);

Fatigue from heavy tasks;

Badly designed machine tools, equipment and instruments;

Badly designed work station layout;

Influence of shortcomings in the immediate environment (Lighting, Noise, Ventilation, Heating, etc.).

From the above factors it can be seen that the design of Work Station Layout is very relevant to CAFLAP, and especially to the design of a Work Station Module - Man

Space (see 4.2.1.3).

The physical factors of Work Station Layout, which have a dominating influence on the operation are:

- maximum physical comfort of the operator;
- good view, enabling the operator to see all phases of the manufacturing process;
- good access to all important parts of work station;
- a reduction of physical strain to a minimum.

Mental factors of Work Station Layout, which are of equal importance to physical ones from the control point of view, are:

- operator should be able to exercise control easily and with accuracy;
- sources of mental strain that distract the operator's attention from making judgements and decisions needed for the job should be eliminated;
- stress from lack of space or unsafe working practices should be prevented.

These ergonomic factors are determining the demands on space in which the operator is working. This, denoted in CAFLAP as MAN SPACE, is discussed further in paragraph 4.2.1.3.

Synergetics:

Synergetics is a relatively new science which is studying sets of effects of work environment on operators [27,28].

It is trying to establish the best configuration and combination of sets of elements and their influences, to achieve optimum performance. From the Synergetics point of view, CAFLAP is trying to find the best arrangement of work stations in detail layout (see 4.3).

A study of all the above aspects has, in the present CAFLAP work, led to a new appreciation of dynamic and spatial relationships within a manufacturing system, and to their reconsideration for the puposes of CAFLAP.
But, before the system is analysed in detail, the shop floor situation, as it is recognised in today's factories, has to be summed up.

A classical Plant Layout (shop floor space) usually comprises the following Areas:

a) Manufacturing Area
b) Manufacturing Services Area
c) Non-Manufacturing Area
d) Stock Area
e) Aisles Area
f) Unrehabilitated Area

Other areas include:
1. Administration Offices
2. Employee Facilities
3. Factory Offices

4. Garages
5. Services (Energy)
etc.

CAFLAP could, of course, consider the layout of all areas, but because the Manufacturing Area is the most important (sometimes it occupies over 50% of all other areas), the present work is concentrated on this area.

As from the point of view of system approach, complex problems can be seen more clearly, this methodology has been used in the following classification.

4.2.1 SYSTEMS

A manufacturing system expressed in dynamic organisation terms for the purposes of CAFLAP {see Fig.3.} can be classified [15] as follows:

A) Higher Systems - region, state, continent, world.. etc.

B) Wider System - Plant,Factory,Company.

Systems, within the wider system, are:

a) System Management and Administration:

- Management control level (Personnel, Purchasing, Financial, Sales, Marketing, Prodn. control, Prodn. planning, Industrial eng., etc.);

b) System Research and Development, Drawing Office;

c) System Services:

- Health and Safety, Catering, Maintenance, Stores, Swarfing, Scrap control, Plant and Building Services, Power, Energy Supply etc.;

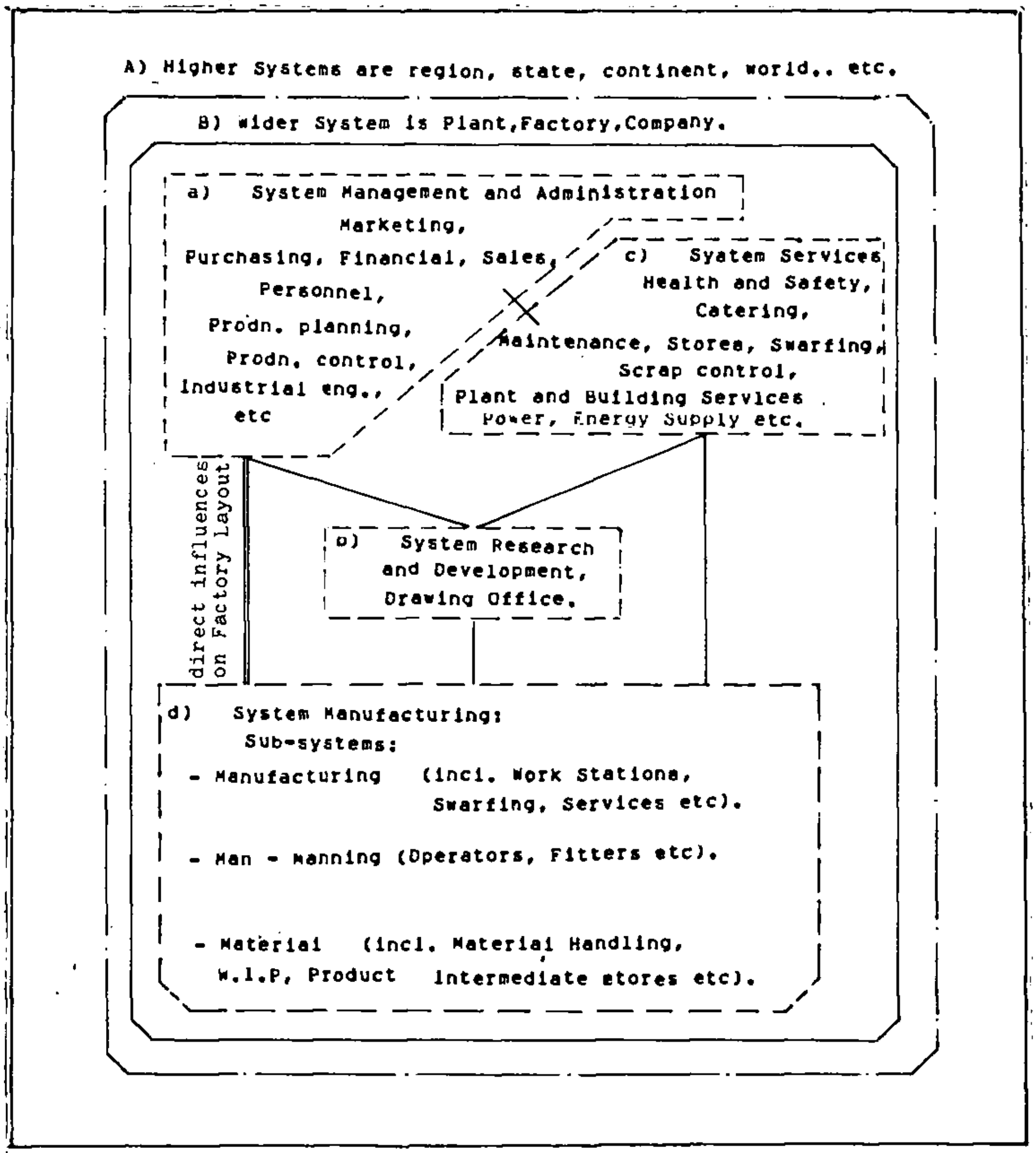


Fig. 3.

MANUFACTURING SYSTEM EXPRESSED IN DYNAMIC ORGANISATION TERMS

d) System Manufacturing:

Here Sub-systems can be distinguished:

- Manufacturing (incl. Work Stations, Swarfing, Manufacturing (Auxiliary) Services etc.)
- Man (Operators, Fitters etc.)
- Material (incl. Material Handling, Intermediate Stores etc.)

The above dynamic organisation systems have to be physically accommodated (in spatial terms) and it is obvious that the systems and sub-systems would have their own specific requirements on physical properties of buildings (floors, areas, spaces).

Hence the Wider System, expressed in spatial terms {Fig.4.}, will comprise:

a. Offices (System Management and Administration, Drawing Office, R+D)

b. Special Areas (System Services, Laboratories, etc.)

c. Shop Floor/Space (Layout)
which has to accommodate the system Manufacturing and its sub-systems:

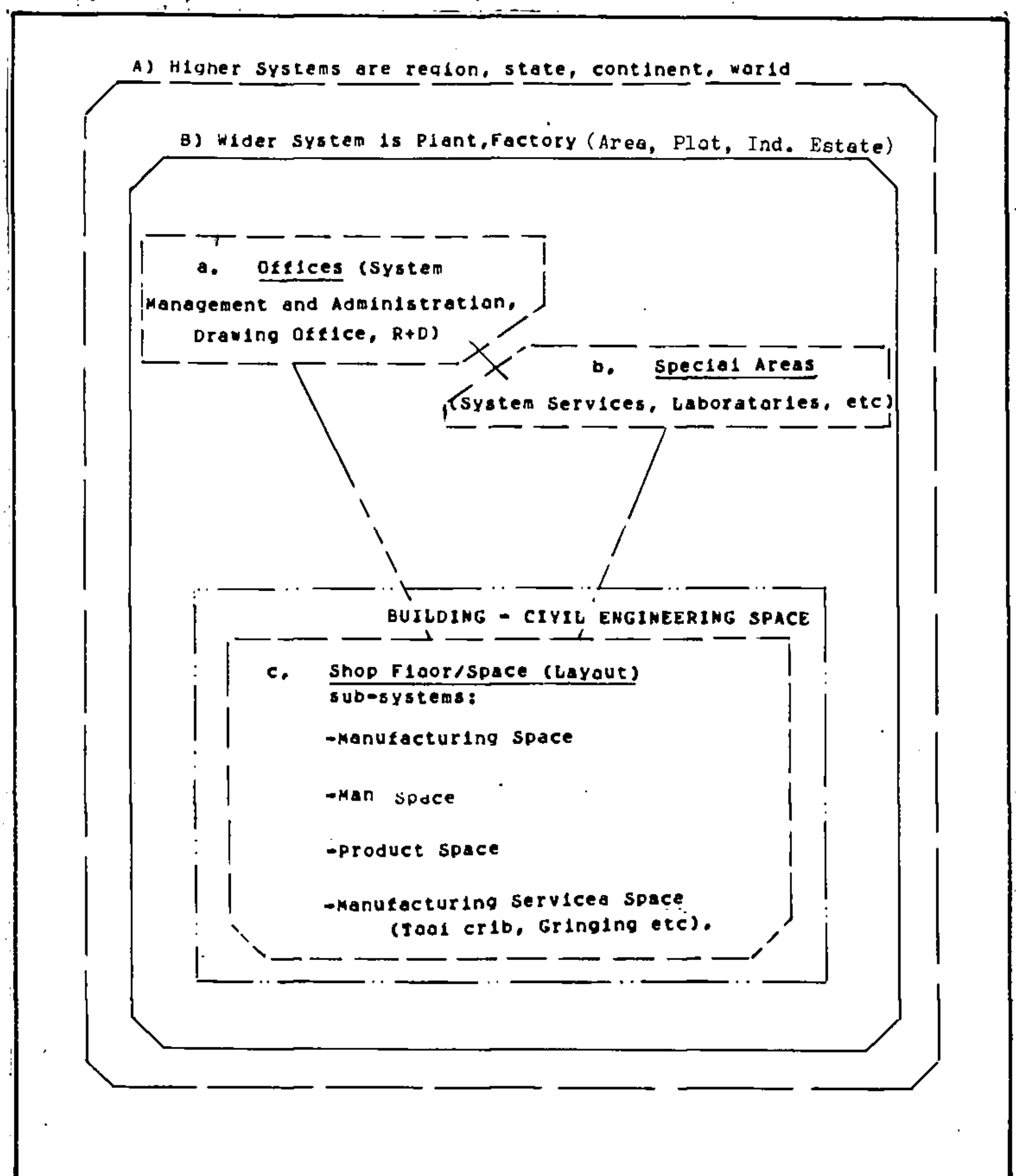


Fig. 4.

MANUFACURING SYSTEM EXPRESSED IN SPATIAL TERMS

- Manufacturing Space
- Product Space
- Man Space
- Manufacturing Services (Appendix I-10) Space (Tool Crib, Cutter Grinders etc.)
- Services (Appendix I-11) Space (Power, Water etc.)

The design of offices and similar areas is usually the domain of architects. The industrial or layout engineer furnishes them with information relevant to administration and production requirements, for example, the number of staff to be accommodated, the office equipment needed, etc.. Special areas are usually designed through co-operation between architects and engineers. In respect of manufacturing areas it is the factory layout engineer who is principally involved. Architects or other professionals also try to exercise their influence in these areas, but such approaches must be considered as secondary because they cannot guarantee technologically orientated, cost effective production.

It is the intention here to highlight the special features of manufacturing areas from a Factory Layout Planning point of view, and a discussion of the spaces of main concern follows.

4.2.1.1 MANUFACTURING SPACE

Manufacturing Space is defined as the whole space where product [84] manufacturing is performed, i.e. it is the space occupied by:

- Work Stations [84](incl. accessories), Work Centres including assembly, inspection, painting etc.
- Operational Space (space for all movements of work station parts, essential for smooth production flow e.g.robotics, and movements of Material or Work in Progress (W.I.P.) [84] within the work station).
- work station Maintenance and Repair Space.

The smallest, self-contained unit of Manufacturing Space is a WORK STATION MODULE which is a sum total of all three spaces and includes Man Space (see below). It is simulated as a 3-D computer drawn template {see Fig.5.}. See also program 'WSBUILDR.FOR', Chapter 4.5.1, and Appendix II.

The WORK STATION MODULE is also part of the Work Station Card containing manufacturing and other information regarding the work station (Appendix III, Drawing No. 1, sheets 1 to 6).

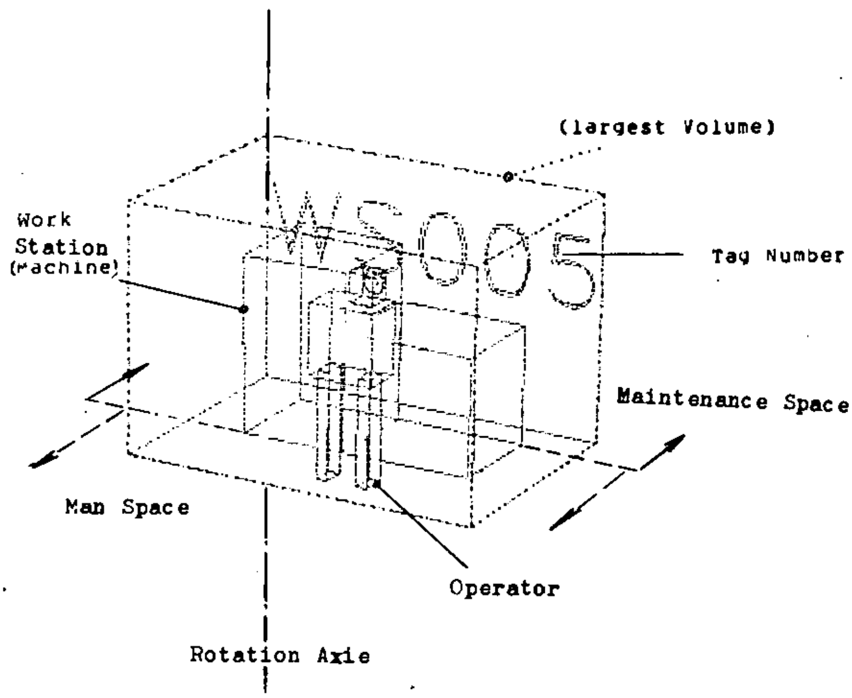


Fig. 5.

WORK STATION MODULE

4.2.1.2 PRODUCT SPACE

Product Space is defined as the space occupied by the Flow of Material, W.I.P., Product, Swarf and Scrap. It includes the space needed for Material Handling equipment and Intermediate Stores.

NOTE: For machine interfaces (deployment of robots etc.) Product Space ends from the very moment when/where the W.I.P. is attached to the work station. A moving work station is considered as a special case of Manufacturing Space.

4.2.1.3 MAN SPACE

Man space is defined as the space necessary for operator(s), fitter(s), etc. to perform all the duties regarding the manufacturing process, and is designed in accordance with the ergonomic principles.

4.2.1.4 MANUFACTURING SERVICES (AUXILIARY) SPACE

Manufacturing services (Auxiliary) space is defined as that space required to accommodate machine services, e.g. Tool Crib, Cutter Grinders, Tool Salvage etc.

4.2.1.5 SERVICES SPACE

Services Space comprises ducts, enclosures, cable trays, etc., and/or maintenance steelwork accomodating supply lines of gasses, power, technological water, coolant, oils etc. for manufacturing purposes.

4.2.1.6 SHOP FLOOR "BREATHING SPACE"

Shop floor "Breathing Space" is the space where NONE of the above spaces are included. (It could be empty). In practice a space like this is usually kept as reserve to accommodate small changes in layout, and expansion. It is usually utilized as additional intermediate store.

It should be noted that all the 'technological' spaces are considered above as well as below zero floor level according to specific situation and needs.

Foundations of work stations, equipment, etc., are considered as being part of the spaces (sub-systems) to which the work stations, equipment, etc., belong (e.g. foundation for a production milling machine is considered in the sub-system Manufacturing Space).

4.2.1.7 BUILDING - CIVIL ENGINEERING SPACE

Building - Civil Engineering Space is defined as the space physically accommodating all 'technological' spaces (Manufacturing Space, Product Space, Man Space, Manufacturing Services Space, Services Space, and Breathing Space), and is providing a suitable environment.

The space includes:

Foundations of buildings (columns etc.)

Floors, Staircases, Platforms, Pits, Ramps etc.

Columns

Storm and sewerage water ducts

Drinking water piping

Walls, Barriers, Doors, Windows

Roof structure

Any unspecified structural supports, stiffeners, etc.

Heating and Ventilation, and

Lighting.

4.2.2 PRODUCTION PROGRAMME

The reasons for wishing to change the layout of a factory such as market forces, orders and production capacity requirements were considered, but are not part of this study. It is assumed only that the Production Programme has been determined that and a new layout has been requested.

The Production Programme basically conditions the type of production (technology, operations, types of machines, and equipment), and this directly influences the type of layout (as quoted in Introduction, Chapter 1.).

4.2.2.1 INFLUENCES OF PRODUCTION PROGRAMME ON DESIGN OF MANUFACTURING SPACE

In Chapter 3. were discussed some computer aided systems which also consider Production Programmes. They sometimes use very sophisticated methods to arrive at a very simple, and usually the only possible, solution: i.e., positioning work stations 'technologically' in an order/line, which is at the same time an economic optimum.

It is also the practical layout strategy (see 4.3) of positioning work stations in a real industrial bay that dictates [13] the order of work stations. This could be, in an overwhelming number of cases, only a physical line of interrelated work stations.

Once a 'technological' position of work stations is computed (by any of the suitable systems mentioned in Chapter 3.), or intelligently established, the actual layout may be designed with CAFLAP system in a straightforward manner. CAFLAP system operations start from the very moment when a 'technological' order of work stations is established, and this data is fed into the system. It can be said that the type of Production Programme, or even type of layout, has no bearing on the design of manufacturing space by CAFLAP system. Neither can it influence the performence of CAFLAP itself.

4.2.2.2 INFLUENCES OF PRODUCTION PROGRAMME ON DESIGN OF PRODUCT SPACE

The Production Programme cannot be considered in isolation and the influences of Production Management techniques (state of organisation) must also be considered. Together they create needs for size of aisles, stores, intermediate stores and Product Space next to work stations.

When designing the size of aisles, the basic unit to be considered is the Unit Load (expressed in dimensions, widthxlengthxheight, and in volume/hr or weight/hr). Unit Load is defined as an optimum load in Material Handling (M.H.) to satisfy all principles of standardization; or simply as " a unit to be moved or handled at one time" as suggested by Tompkins and White [39].

For the purposes of deriving the computer graphics expression, the basic equations from Hydrodynamics was considered:

$\omega = Q / F$ where ω = speed of movements of Unit Loads (m/hr)

Q = Volume of Unit Loads manufactured per unit of time (cu.m/hr)

F = sectional area available for transport (sq.m)

$$F = w . f$$

and

$f = Q / \omega . w$ — w = Aisle width (m)

f = "filling" of the Bay (m) is height of the Aisle utilised for M.H., (indicates the density of M.H.).

It has to be said that the above considerations only serve as an auxiliary guide because the real movement of material in batch production is in paces. However, such equations help to define the optimum dimensions of transport aisles when translated into computer graphic histograms.

Further the value 'f' (filling) can:

a) Indicate any slowdown in M.H. area, or production area and, once the optimum value is established, any deviation could be monitored, i.e. it could be used as a tool for the Production Control Department;

b) Show what speed of movements in Product Space is required; how many M.H. vehicles, fork-lift trucks, or what sort of M.H. means of transport are needed.

Computer Program 'M100.FOR' was contemplated to provide basic data for the above.

In order to design the size of Product Space at work stations, the following basic systems have to be considered: Two Bin system, Just-in-Time system (KANBAN) and Base Stock control [77,78,79,80]. For any of these systems presentation of Product Space creates special problems, and these are dealt with in section 4.3 Layout Strategy.

The product mix and size of batches can influence Product Space (see 4.2.1.2) considerably, but only if the batches are very small. This has, of course, to be considered in conjunction with M.H. cycle and unit loads.

A unit load (Ul) has requirement for space (Us);
the total time required for machining of a batch is Tb,
and the duration time of a regular M.H. cycle is Tmh.

If a unit load is equal to one batch, and time Tb is N times smaller than M.H. cycle (Tmh),

$$Tmh = Tb \times N \quad (\text{or } Tmh = \sum_{1}^{n} Tb)$$

then Product Space (Ps) -space next to work station available for unit loads waiting for machining or transport- must be increased N times.

$$Ps = N \times Us \quad (\text{or } Ps = \sum_{1}^{n} Us)$$

Or, vice versa, material handling cycle must be shortened (which would increase M.H. costs).

The above consideration is of general validity, including the increasingly popular Just-in-Time system (JIT).

If the JIT (KANBAN) system in production control is used, each Kanban (Shop sign, card) represents a unit load -or container load, according to Burbidge [77]. Apart from identifying the contents of a material container, Kanban is used to order a replacement supply when a container is issued. Kanban practically defines the size of a batch. The number of Kanbans issued indicates the number of batches (unit loads) in the process, and determines the size of the base stock. In other words: the more Kanbans, the larger the base stock. This leads to demands for increased Production Space generally.

It must be concluded that, apart from style of production management, the Product Space is influenced mainly by the type of M.H. equipment.

Other product spaces, Stores and Intermediate Stores should be designed intelligently, but could be incorporated into automatic layout system as individual modules.

Overall Conclusion:

Insufficient Product Space generally results in difficulties, especially in the following areas:

- shop floor management/production management
- material handling (clumsy and slow M.H., bad access)
- safety

Excessive Product Space results in an overall increase of shop floor/ space and this creates waste in the following spheres:

- material handling costs (bigger distances),
- ventilation and heating costs,
- lighting costs,
- maintenance costs, and
- larger capital investment costs.

The above indicates that the design of an optimum Product Space is quite a difficult task considering the variability of factors involved. It is made even more complicated by the requirements of computer graphic presentation and this leads to the development of a novelty idea: the concept of a PRODUCT SPACE ZONE (see the following section 4.3).

4.3 LAYOUT STRATEGY

One of the objectives of CAFLAP project is to shorten the time of the traditional layout approximation process (as described in Chapter 2.), while maintaining the principles of a good factory layout. This can only be done by preparing the detail layout first, skipping the two initial project stages: Feasibility Study and Investment Project {see Fig. 6.}.

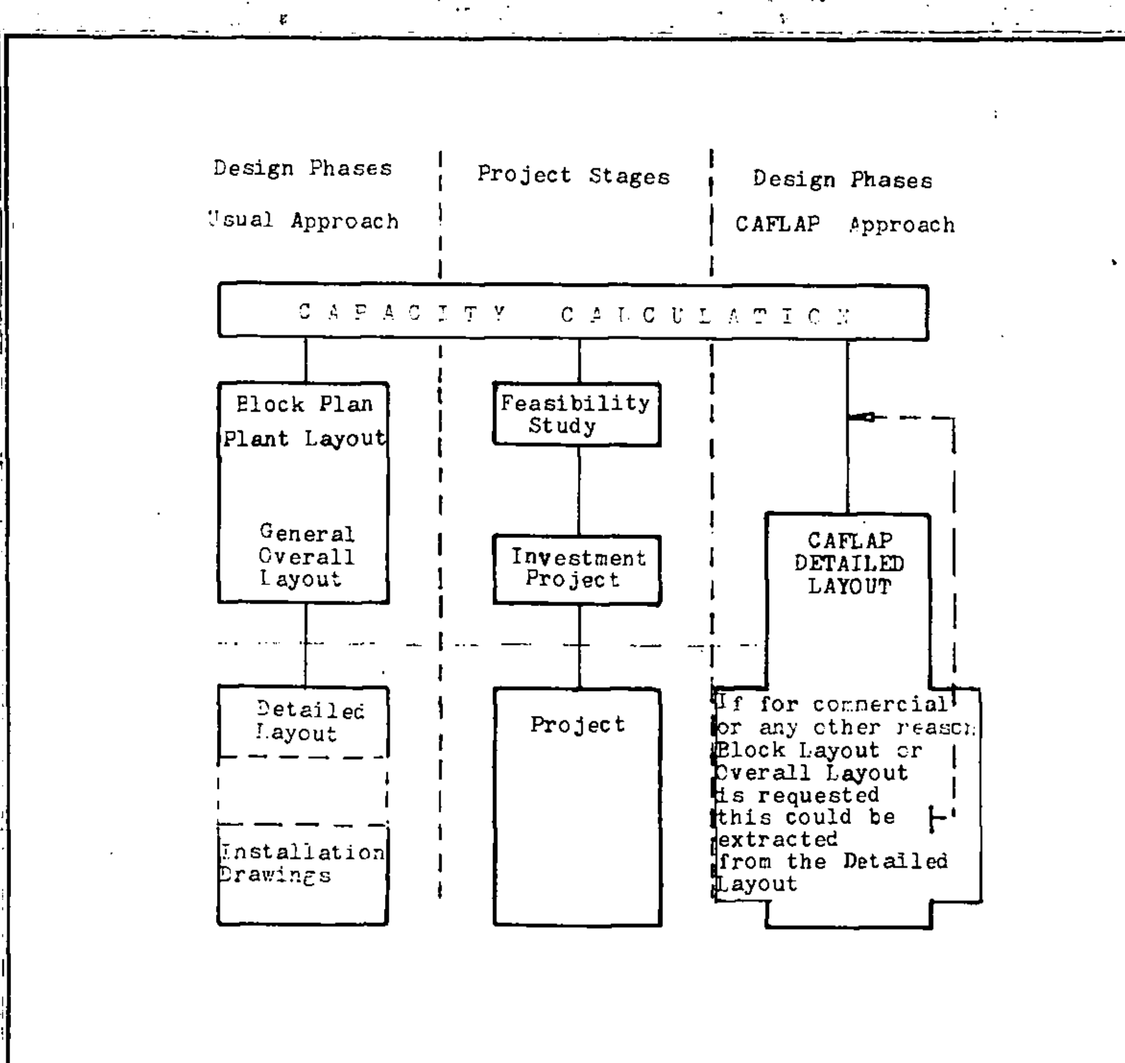


Fig. 6. PROJECT STAGES - DESIGN PHASES - CAFLAP APPROACH

4.3.1 CAPACITY CALCULATION

It is assumed that the number and types of work stations needed will be extracted from Route Sheets (or Job Cards), and the 'technological' positions of work stations will be established (as mentioned in Chapter 3.). The number of machine tools (M/C) can also be calculated via program 'M100.FOR'.

4.3.2 DETAIL LAYOUT

Experience has shown that the actual layout can be prepared effectively only when it is started in the direction of the Flow of Material, and in the 'technological' order of a line of work stations involved.

In Fig. 7., Layouts a) to g) are presented as typical detail layouts of regularly arranged work stations in Industrial Bays.

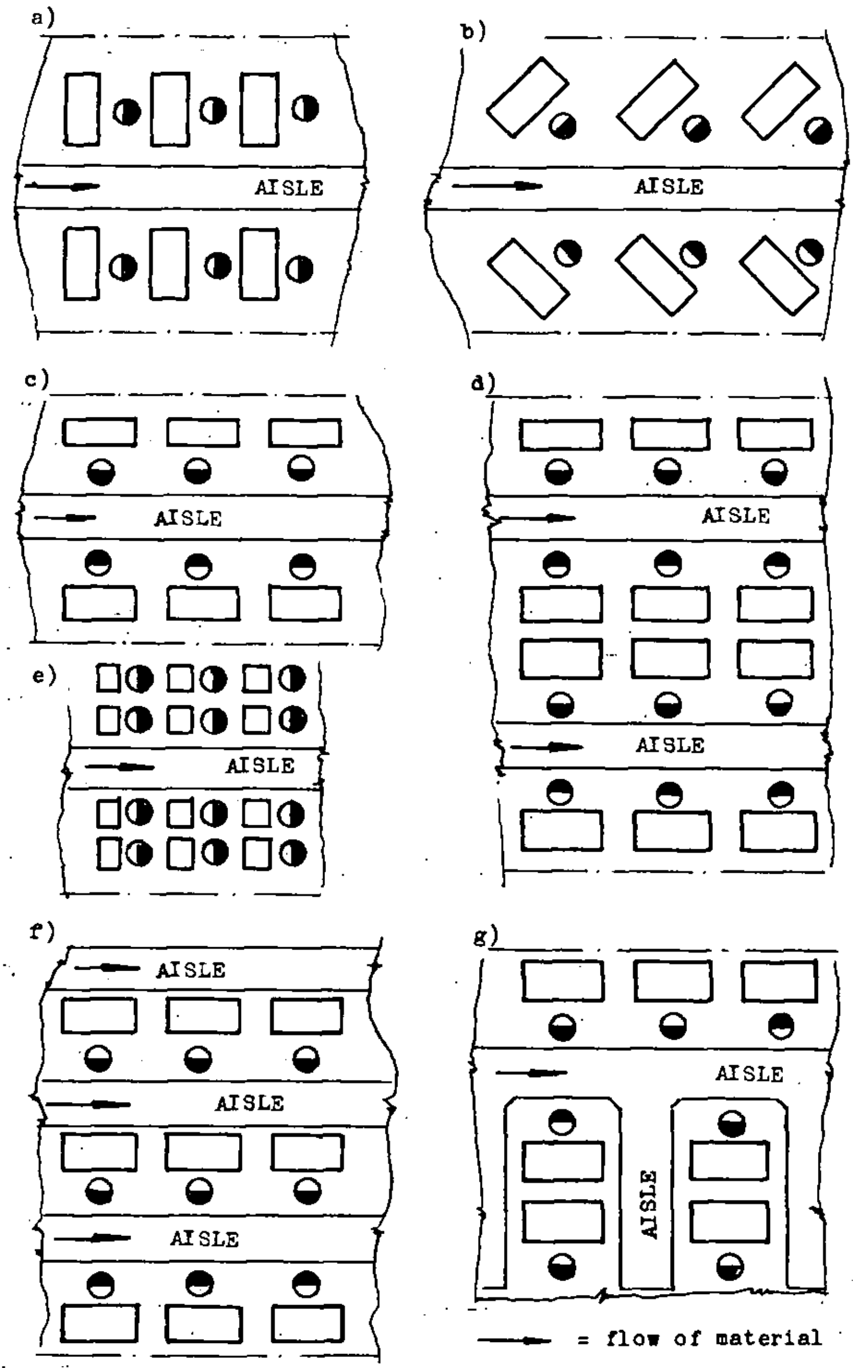


Fig. 7.

TYPICAL DETAIL LAYOUTS OF REGULARLY ARRANGED WORK STATIONS

(Plan views)

Types a) and b) are considered ideal:

- to satisfy the criteria of a good layout, and
- to provide maximum comfort for the operator (create a set of environmental configurations in order to optimise his performance - all ergonomic principles are maintained).

For the above reasons these two types have been selected to be used for automatic positioning in CAFLAP system developed here. The main steps in detailed layout are shown in a system chart {Fig. 8.}.

STEP 1.

The list of work stations is determined and individual Work Station Modules are drawn and filed. The basic width of the industrial bay and the width of the Product Space Zone are determined intelligently according to the width of an everage size Work Station Module and the width of Unit Load {see Fig.9}.

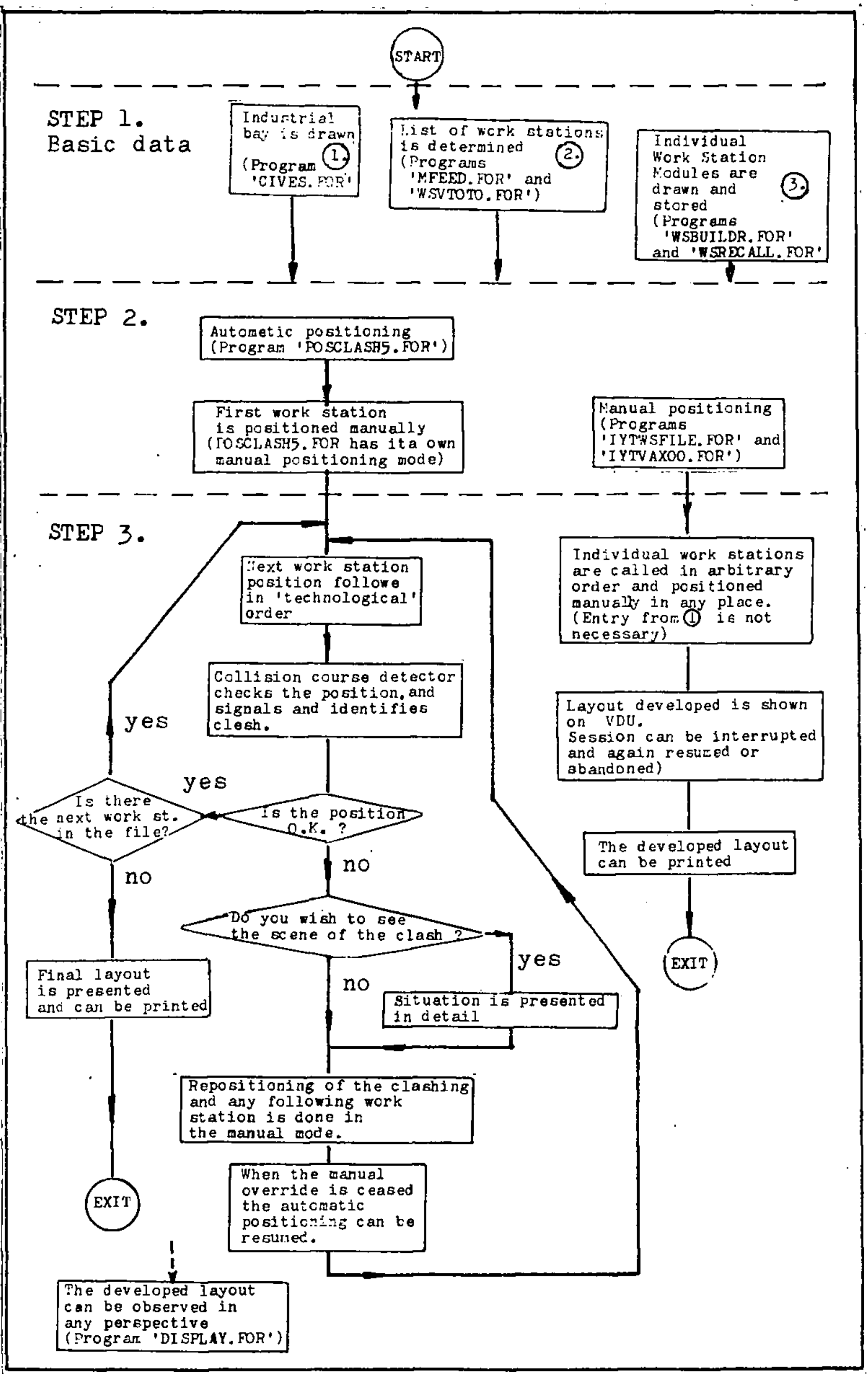


Fig. 8. CAFLAP SYSTEM
SIMPLIFIED SYSTEM CHART

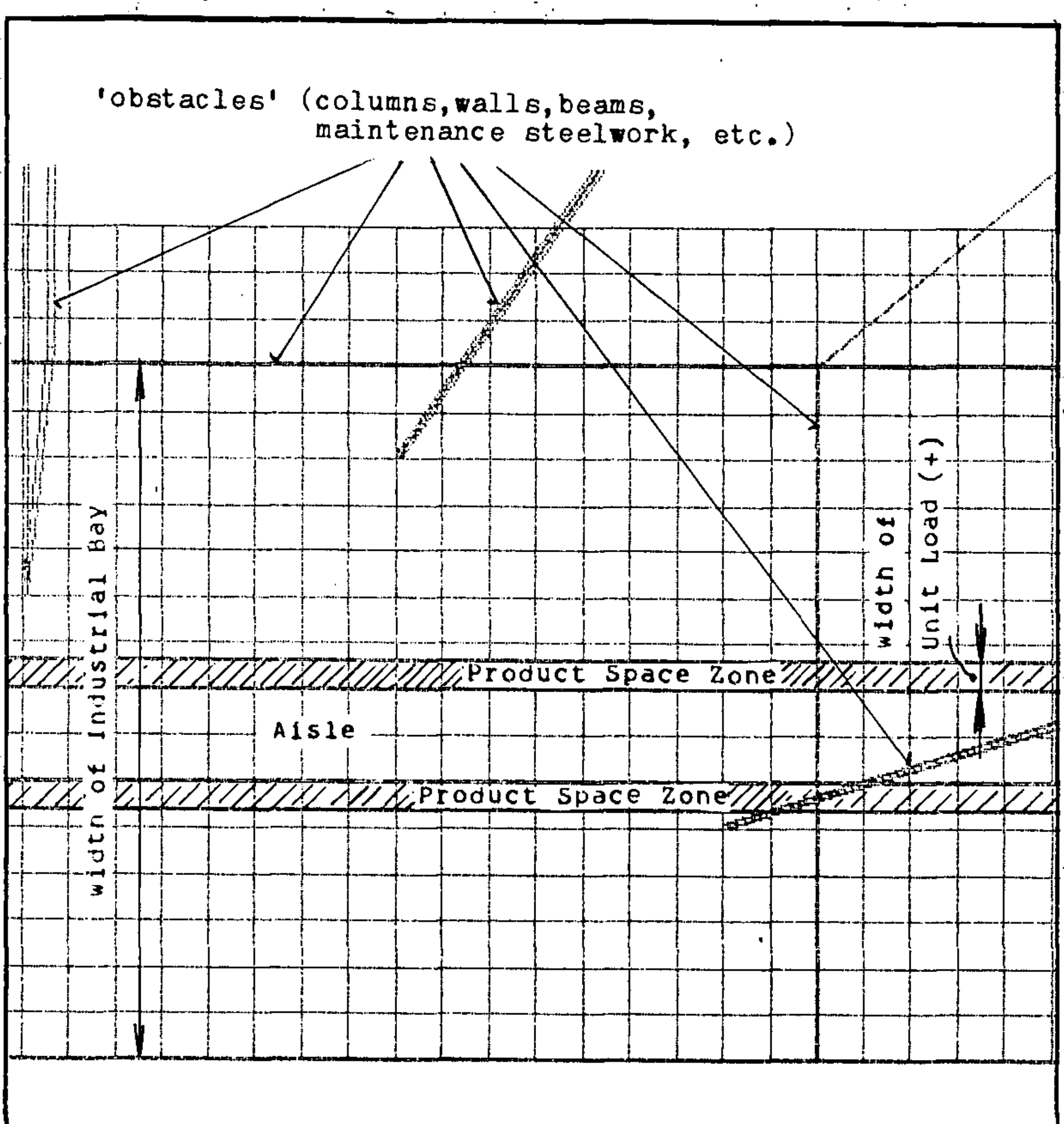


Fig. 9.

DESIGN OF AN INDUSTRIAL BAY
(3 - D representation, viewed from above)

The PRODUCT SPACE ZONE is defined as a 'hard shoulder' type area; a continuous strip of space running alongside aisles, which is designed:

a) to serve for storage of material, W.I.P. and products (Unit Loads, pallets etc. [39,83]) next to work station, and

b) as a 'boarder' for automatic positioning mode in CAFLAP.

The width is determined by the width of Unit Load. The Product Space Zone can accommodate all the different demands (i.e., Two-bin, Just-in-time, and Base-Stock Control) on Product Space resulting from the above mentioned systems. The only space loss is limited to the width of the Man-Space, allowing a safe passage for the operator.

If the automatic positioning mode was considered in isolation from the rest of the CAFLAP system, it could be classified according to Moore [30] as an improvement type procedure because it starts with a predetermined industrial bay.

STEP 2.

The first work station is positioned manually in a requested place/section of the industrial hall either at a right angle to the aisle or obliquely to it {see Fig.6. a) and b)}.

STEP 3.

The rest of the layout development follows according to the mode selected (see section 4.5.4). If a collision course is indicated, a facility for manual positioning (manual override) is used in order to reposition one or more work stations as necessary to avoid the collision. If then requested, the automatic positioning mode can be resumed.

This method can also be used to find the optimum width of an industrial bay (see Fig.10.), i.e. if the work station is found to be colliding with the 'border' (Product Space Zone, aisle, walls etc.) it is repositioned into an oblique position. This, intelligently assessed, could lead to an even narrower bay design, especially if work stations are long and 'slim' (e.g. a turret lathe).

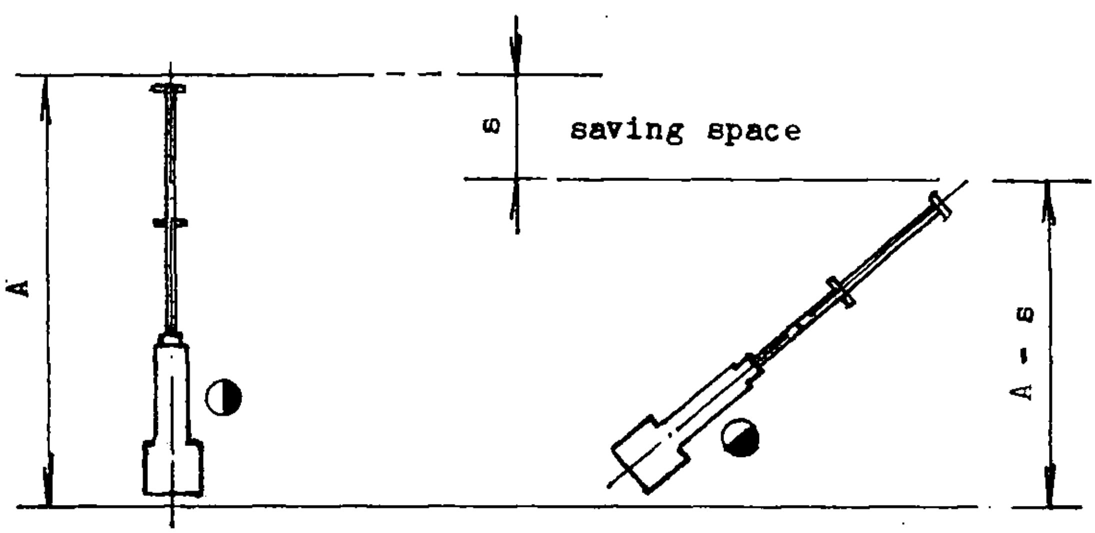


Fig. 10.

FINDING THE OPTIMUM WIDTH OF INDUSTRIAL BAY

The value of this procedure for a 'green field' layout design is obvious.

A narrow industrial bay is much more cost effective than a wide span industrial bay, which is not only expensive to build (initial high capital investment), but also to maintain. The larger span bay requires a higher roof structure which also increases the volume of air to be ventilated and heated: a further consideration for costs. The construction height of the building cannot be fully utilised technologically. If cranes are used, it is again the larger span of the bay that dictates higher cost of cranes and may influence their performance.

In a practical layout, there are two types of work station formations: regular and irregular (see Fig.4). CAFLAP system has been developed to accommodate both: for the irregular formation case the manual positioning mode of CAFLAP may be used, while the automatic mode serves in the case of regular positioning.

4.3.3. OVERALL LAYOUT OF INDUSTRIAL HALL

CAFLAP can be used as a tool for design of an industrial hall of any shape. The following describes a typical case. A flow chart in Fig. 11. shows the methodical steps in layout design of an industrial hall. For typical production line flow patterns see Fig. 13.

1. A 'Continuous longitudinal bay' is designed, regardless the shape and size of the existing or newly designed industrial hall (program POSCLASH5.FOR).Total length of the bay 'L' is obtained.
2. If the hall length 'Hl'(e.g. depending on the size of the plot available) is n-times shorter than 'L', then 'L' is cut in 'n' bay sections.
3. The shape of the flow pattern is chosen (U-shape, S-shape, parallel).
4. The bay sections are fitted into the hall, following the chosen flow pattern.
5. The bay sections are checked against the corresponding civil engineering space. The layout is revised and adjusted if necessary. (POSCLASH5.FOR)
6. Improved layout is printed.
7. Alternative designs of the industrial hall (changing the flow patterns and detailed layout) follow.
8. Alternative designs are evaluated using the ratio of spaces, and minimum space needed is sought.

Fig. 11. MAIN STEPS IN THE DESIGN OF INDUSTRIAL HALL-OVERALL LAYOUT

A detail layout of 'technologically' self-contained sections (i.e. an interdependent line or group of work stations), is continued in a straight 'continuous' line. This also satisfies Muther's [4] layout fundamentals {see Fig. 12}. A 'continuous longitudinal bay' is thus designed {corresponding to Fig. 13. a)}.

The principle of a 'continuous industrial bay' is an aid for layout planning using automatic positioning mode (see section 4.5.4). It provides for fluent positioning of work stations in the bay.

The continuous bay is designed in its total length regardless the length of the industrial hall. The hall usually accommodates more than one bay {see Fig. 13.d)}. The work stations may be positioned on both sides of the aisle.

When the length of the industrial hall 'Hl' is shorter then the length of the continuous industrial bay 'L' and a U-shape or S-shape Flow Pattern is used {see Fig.13. b)}, the total length of longitudinal bay has to be cut (while 'technologically' self-contained sections are maintained), into lengths which can be accommodated in the industrial hall.

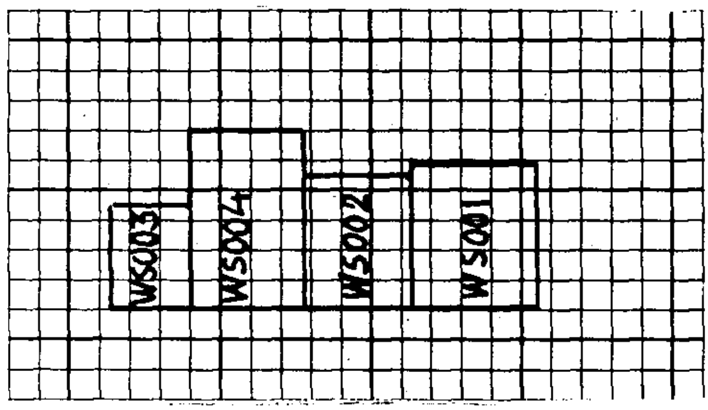
When a Parallel Lines Flow Pattern {see Fig.13. c)} is used, individual lengths have to be cut accordingly.

RELATIONSHIP
degree of closeness
desired
among M/Cs

OP01 → OP02 → OP03 → OP04 →

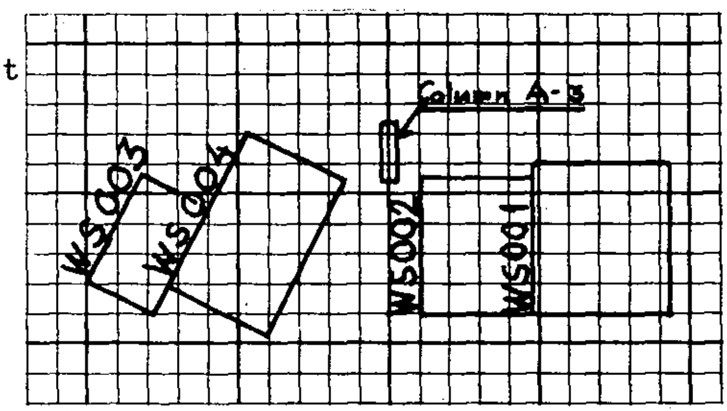
operations

SPACE
configuration



ideal position of work stations

ADJUSTMENT
realistic best fit



realistic position of work stations

Fig. 12. 'CONTINUOUS' LINE SATISFIES LAYOUT FUNDAMENTALS

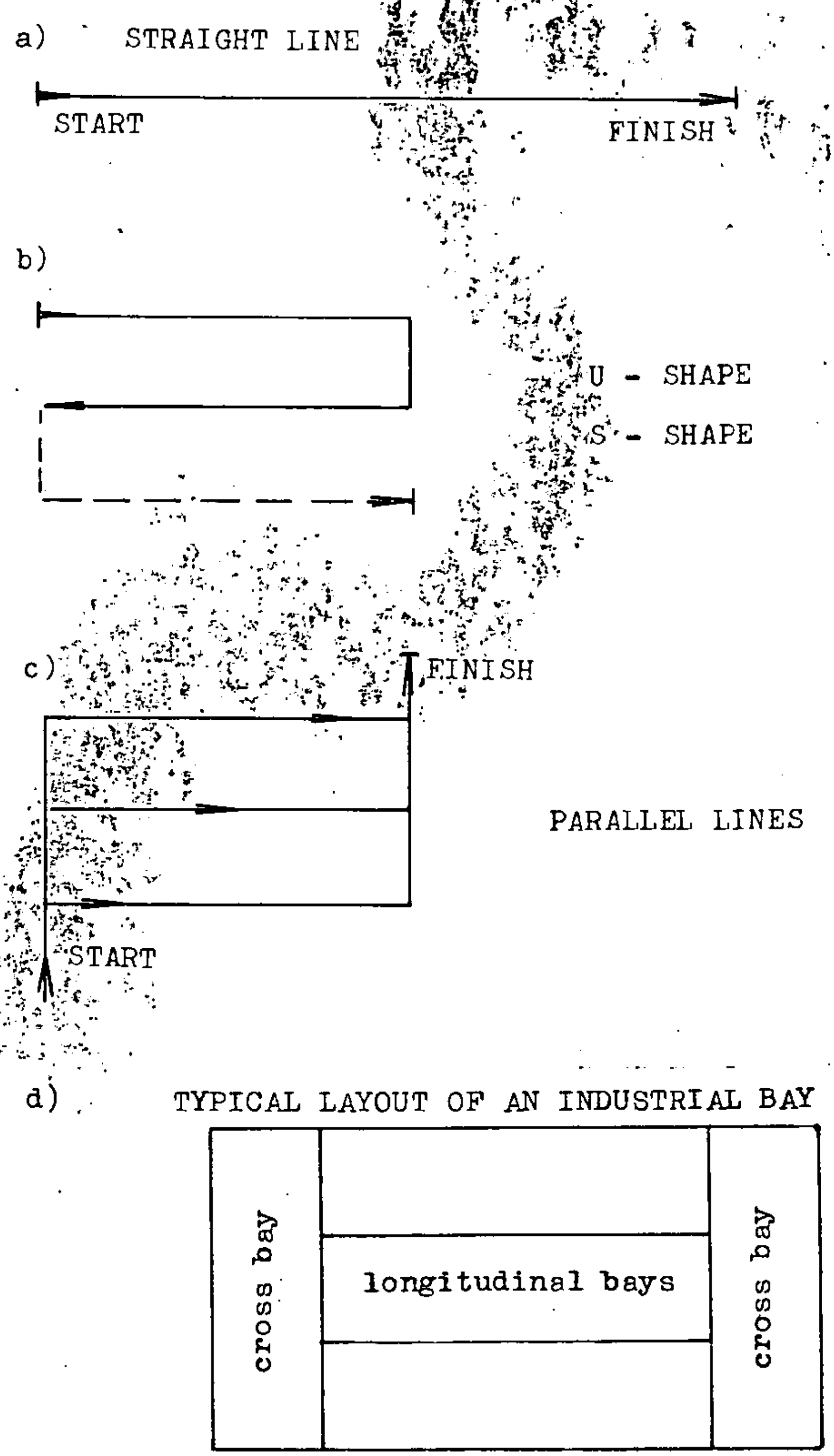


Fig. 13. FLOW PATTERN FOR PRODUCTION LINES

4.4 LAYOUT USING INTERACTIVE COMPUTER GRAPHICS

In the preparatory stage of this project it was essential to select an existing commercial software system suitable for the purposes of CAFLAP methodology. The selection was influenced by CAFLAP demands for a computer graphics system and also by several other factors, which are summarised as follows:

The system should have a facillity for a simple design of all objects/spaces in 3-D. This refers especially to the design of Work Station Modules and to the Civil Engineering Space with all its elements.

The system should have a facility for marking the designed objects with identification or tag numbers.

The system should have a suitable potential for the development of facilities for manual and automatic positioning of 3-D objects and collision course finding. Kinetic function ability is essential for the positioning of Work Station Modules in the Civil Engineering Space and for Collision Course Finding. It is also important for the observation of the developed scene.

The obvious choice available was a CAD drafting system, for example MEDUSA (in possession of Middlesex Polytechnic).

The system was tested and part of the Project was investigated with the participation of some engineering undergraduates.

In spite of the fact that MEDUSA offers an exellent drafting facility, it was realised that modification of the system for the purposes of CAFLAP would be far too complicated (if not impossible). Therefore the development using this system had to be dropped.

Another system in operation at Middlesex Polytechnic is PICASO (PIcture Computer Algorithm Subroutine Orientated) developed by Dr.John Vince [93, 94].
It is a FORTRAN-based computer graphics system, designed to ease the interface between programmer and graphical problem areas. PICASO subroutines may be incorporated into any FORTRAN or PASCAL based programs. It offers a comprehensive library of 2-D shapes and 3-D objects which may be manipulated through a wealth of manipulating algorithms. The system's conceptual space allows the user, through the 'observer', projection mode and projection space (using system commands), to observe and manipulate any designed scene. For shapes and object analysis the system is equipped with some thirty six analysis commands. For shapes and objects presentation there are over thirty drawing commands. Drawings generated by PICASO are normally drawn on high resolution VDU and could also be plotted upon any suitable plotter. Since PICASO was apparently developed for

visual arts, it has a variety of built-in features to suit that purpose. Because of its versatility, it offers considerable potential for creative use even to engineers. It also has a capacity for modification and for further development. These are the reasons why PICASO was adopted for use in CAFLAP work.

The hardware used was originally Prime 550 computer which was replaced by VAX/VMS VERSION V4.5 computer system. Terminals used were Applied Digital Data System, Model ADDS-Regent 25; Insight Terminals Ltd., Model vdt-1; and printer EPSON FX-80.

4.5 PROGRAMS AND THEIR SOLUTIONS

The CAFLAP programs developed here were compiled in FORTRAN 77. The major reason for using FORTRAN was because the research project exploited the PICASO computer graphics library, which was implemented in FORTRAN 77. Although PICASO can be treated as a library of subroutines and functions, and therefore is accessible to other languages such as: PASCAL and C, it was decided to implement all programs in FORTRAN as the CAFLAP system needed to modify some of the original code of PICASO. Maintaining this language consistency only involved the Writer in learning one language. Furthermore, Middlesex Polytechnic - where the research was undertaken - had used FORTRAN as its primary scientific/mathematical language and was able to provide a reliable software support service.

Although FORTRAN has played a very inportant part in the development of scientific/mathematical software, and is still used to implement original code for some companies, the language in favour at the moment is C. It offers a more rigorous programming environment with strengths in: data structures, structured programming, interaction with UNIX and reduced program development times.

CAFLAP could be implemented in C, and also in other languages such as PASCAL, or BASIC, but would require modification to exploit the benefits offered by PICASO. If CAFLAP was to be made independent of PICASO, it would require substantial support in the area of computer graphics.

Developing any program requiring computer graphics facilities presents problem to the programmer, mainly because of the variety of graphic specification available for workstations. To help overcome these implementation problems some computer graphics standards have now been developed, e.g. GKS, GKS-3D and PHIGS. None of these systems were available to the Writer during his work; nor was it possible to have access to sophisticated colour grahpics workstations that would have had an impact upon CAFLAP's interface.

CAFLAP was developed as a vehicle to explore the Writer's ideas in developing strategies for automatic factory layout, and in this respect it was successful. To be considered now as the basis for a commercial system, it has in future to be rewritten specifically to meet the demands of any particular commercial environment.

The development of layouts, using computer graphics, generally followed the steps outlined in the Layout Strategy (Chapter 4.3).

In order to maintain an efficient programming technique [96] the main programs have been kept short (i.e. not more than 100 lines), and the subroutines have been mostly built-in, in a tree-like hierarchy. The imput data are manipulated via COMMON areas, subroutine arguments, external files and an interactive terminal, for the convenience of the user, in some cases in conjunction with a printer. Each program is internally documented by comments in natural language, for the benefit of the user or another programmer. The comments are divided into two categories: Macro Introductory Comments and Micro Continuous Comments.

The Macro Introductory Comments describe the general qualities of the program:

- name of the program;
- the purpose for which the program was built;
- if the program is long and complicated, there is a

short description of previously written sub-programs of which it consists or with which it co-operates;
- size of the program, i.e. for which number of work stations it is designed;
- program output.

The Micro Continuous Comments are those relating to the main operations, and these help to clarify and expand the significance of the FORTRAN written code.

The layouts of programs produced here have purposely been kept simple for easy reading and understanding. Great care has also been given to Statement Numbering so as to keep them in an ascending numerical order sequence, which is easy to follow. The resultant layout, and especially the included comments, thus make the programs largely self-explanatory.

The programs were developed as an integral and major part of this work but, because of their large physical volume, it was not considered appropriate to include them here. They are instead described in the following sections and included, in their entirety, as Appendix II.

4.5.1 WORK STATION MODULE BUILDER

Work Station Modules are built by the program 'WSBUILDER.FOR'. A 3-D template is built-up from a hand-drawn sketch of the Work Station Module. The sketch includes Maintenance Space, Operational Space, Man Space, and work station (i.e. the machine tool itself including accessories), maintaining recommendations from manufacturers and all ergonomic principles. The steps in Work Station Modules design via the interactive program are following:

- requested objects (boxes, cylindrical parts, anchoring bolts, operator(s), Tag Number etc.) are selected according to a pre-printed code;
- instructions are given in the program regarding size and position requirements;
- the engineer feeds in requested dimensions and positions of the objects, starting from the origin (x=0,y=0,z=0);
- this process continues, object after object, until a complete Work Station Module is built;
- the work station is then filed under a unique Tag No. for future reference/recall, and the procedure is ended.

'Drawing' of the next work station can follow.

Any Work Station Module picture may be recalled by program 'WSRECALL.FOR'.

NOTE:

Information for the hand-made sketches of Work Station Modules is usually taken from the machine tool manufacturer's drawings, foundation plans and manuals (including installation and maintenance recommendations and instructions).

Some well established manufacturers of machine tools helpfully supply, with their installation manuals, pre-printed simplified 2-D templates of their machine, on the basis of which the sketch of the Work Station Module could be prepared. The original intention was to identify Man-Space, Maintenance Space and Operational Space in the drawing by hatching. But this was found impossible in a 3-D representation because hatching would obscure the picture. Therefore the Spaces are drawn inside the 'largest volume' of Work Station Module {Fig. 5.}, without any further identification (hatching or tinting).

4.5.2 BUILDING (CIVIL ENG. SPACE) DESIGN PROGRAM

For the purpose of designing an Industrial Bay interior, Program 'CIVES3.FOR' has been compiled. A fully-detailed 3-D image of an industrial bay may be built from PICASO objects (presently only Boxes are used).
The method is following:

Individual civil engineering elements and 'borders' (i.e. Product Space Zones, aisles, etc.), are input.
The 3-D image is shown on a VDU and individual elements can be changed, replaced, or added until the simulation of the bay interior is completed.

NOTE:

In case the layout is being planned in an existing building, the Civil Engineering Space will be built exactly according to the civil engineering drawings available.

The writer's experience is that even well established old factories often possess unreliable civil engineering information, so that, an industrial hall survey may have to be taken and new reliable drawings produced.

4.5.3 MANUAL POSITIONING PROGRAMS

For the manual positioning of Work Station Modules (largest volumes only) in the bay, or for the positioning of departments, bays in the hall and halls in a plot, a program 'IYTVAXOO.FOR', using a joystick, has been compiled. Examples of drawings prepared by this program are shown in Appendix III, Drwgs Nos. 02. and 03.

Any objects, represented here by boxes, can be entered into a list and marked individually by Tag Nos. or any other identification (e.g. name of a department). They are then positioned against the background of a grid representing the requested area.

For manual positioning of work stations only, program 'IYTWSFILE.FOR' has been compiled. This program has a facility to retrieve detailed Work Station Modules and incorporate them into a required layout in a similar way as in the program 'IYTVAX00.FOR'.

4.5.4 AUTOMATIC POSITIONING PROGRAM WITH COLLISION COURSE FINDING PROVISION

For automatic positioning of Work Station Modules inside the industrial bay, program 'POSCLASH5.FOR' has been compiled.

The functions, satisfying the layout strategy of section 4.3.2, shown on a VDU or printer, are as follows:

- list of work stations available with facility for any required changes {Fig. 14.};
- present situation of development {Fig. 15.};
- new development of the layout in manual and automatic mode, and in any combination of modes {Fig. 16. and 17.};
- facility for collision course finding of Work Station Modules with building elements, 'borders' and other 'obstacles';
- automatic stop at any work station colliding, with identification of work station Tag.No.;
- facility to show {Fig.18.} the situation at a clash;
- manual override allowing to find intelligently the best new position for the colliding work station in the bay;
- continuation of the development of layout in manual or automatic mode {Fig. 19. and 20.}, with a facility to

stop or to continue the development of new alternatives of the layout.

The system is controlled (positioning, repositioning etc.) by unique identification numbers or Tag Numbers.

NOTE:

The rotation axis for Work Station Modules manipulation is the Y-axis running through the far corner of the module on the left of the operator, as shown in Fig.5.

The Tag Number is a part of the Work Station Module and has to be treated as such.

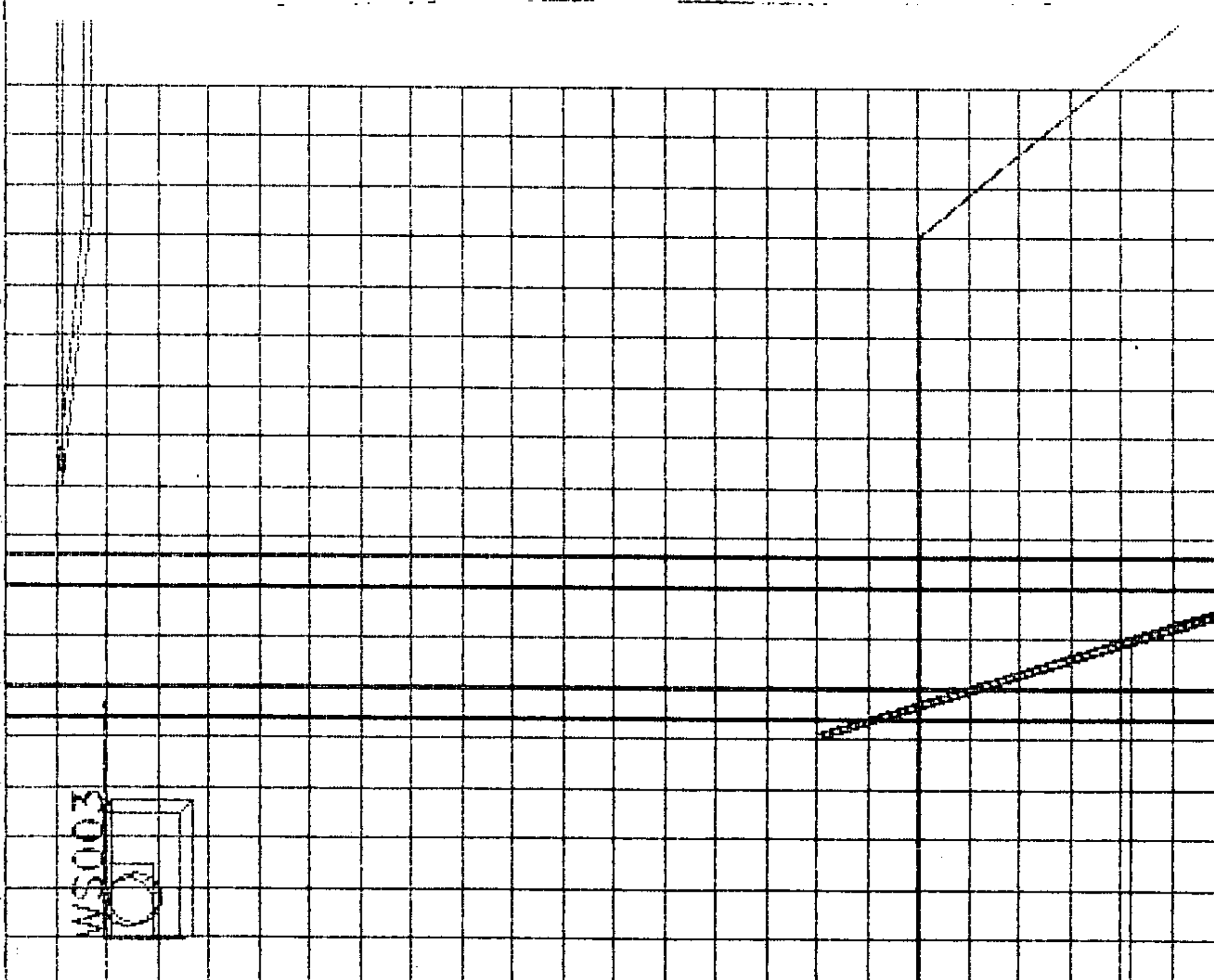
The display area on a 12 inch VDU, which could be used for layout development, measures 18x33 meters in scale, with 77 maximum Work Station Modules.

Fig. 14.

```
File of existing Work Station Module volumes
    1  300.00  200.00  270.00 WS001
    2  280.00  200.00  220.00 WS002
    3  250.00  150.00  150.00 WS003
    4  350.00  190.00  210.00 WS004
Do you wish to extend/update the existing file...YE or NO
```

Fig. 15.

LAYOUT...The existing situation of development



Do you want to continue/change the layout...YE or NO ?

Fig. 16.

You are now in POSITIONING MODE
Are you starting a NEW layout,from the first W.St.in technological order?
..YES or NO
Do you wish to POSITion the considered WorkStation manually ... YE or NO

Please POSITion the W.S. by cross-hairs...

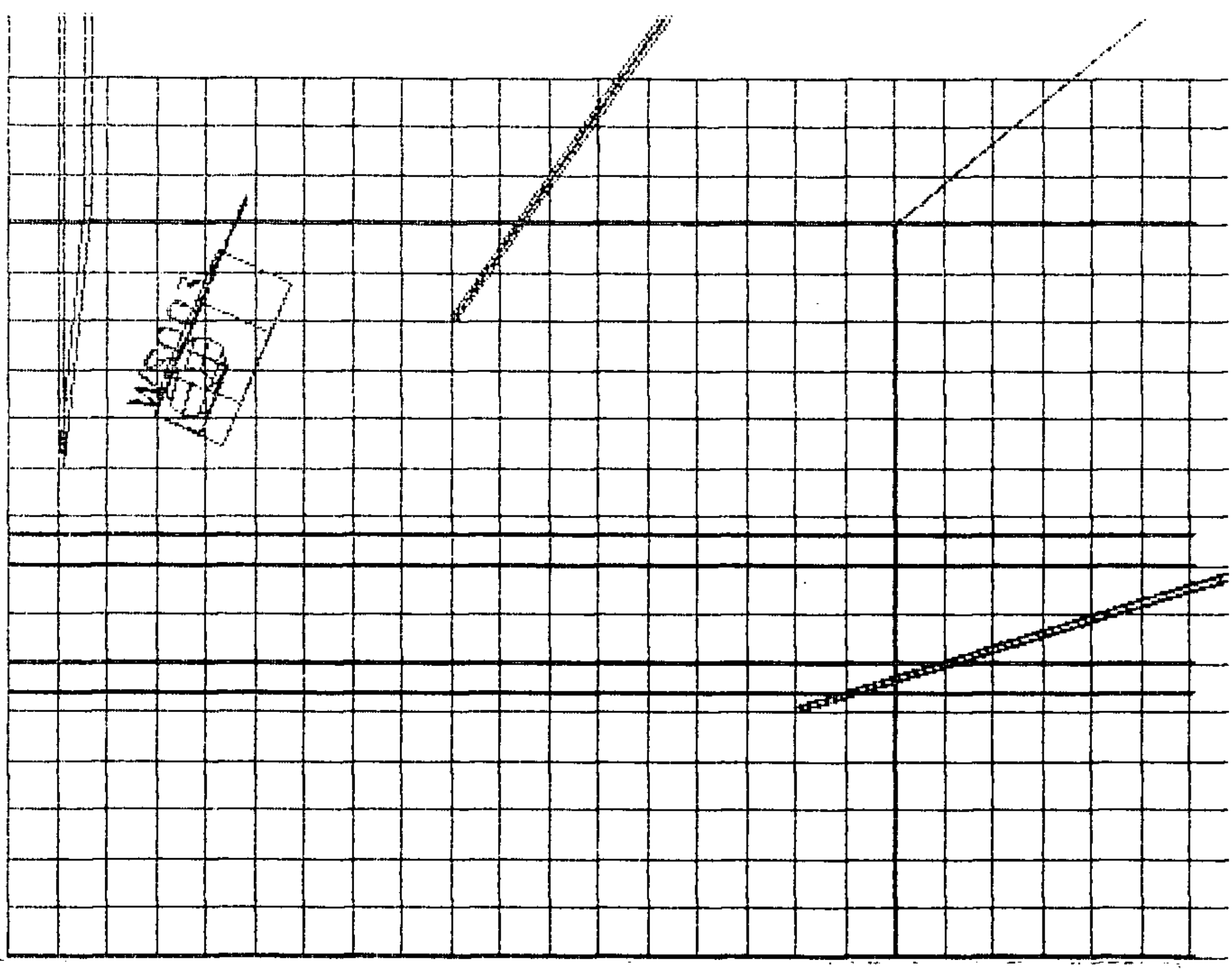


Fig. 17.

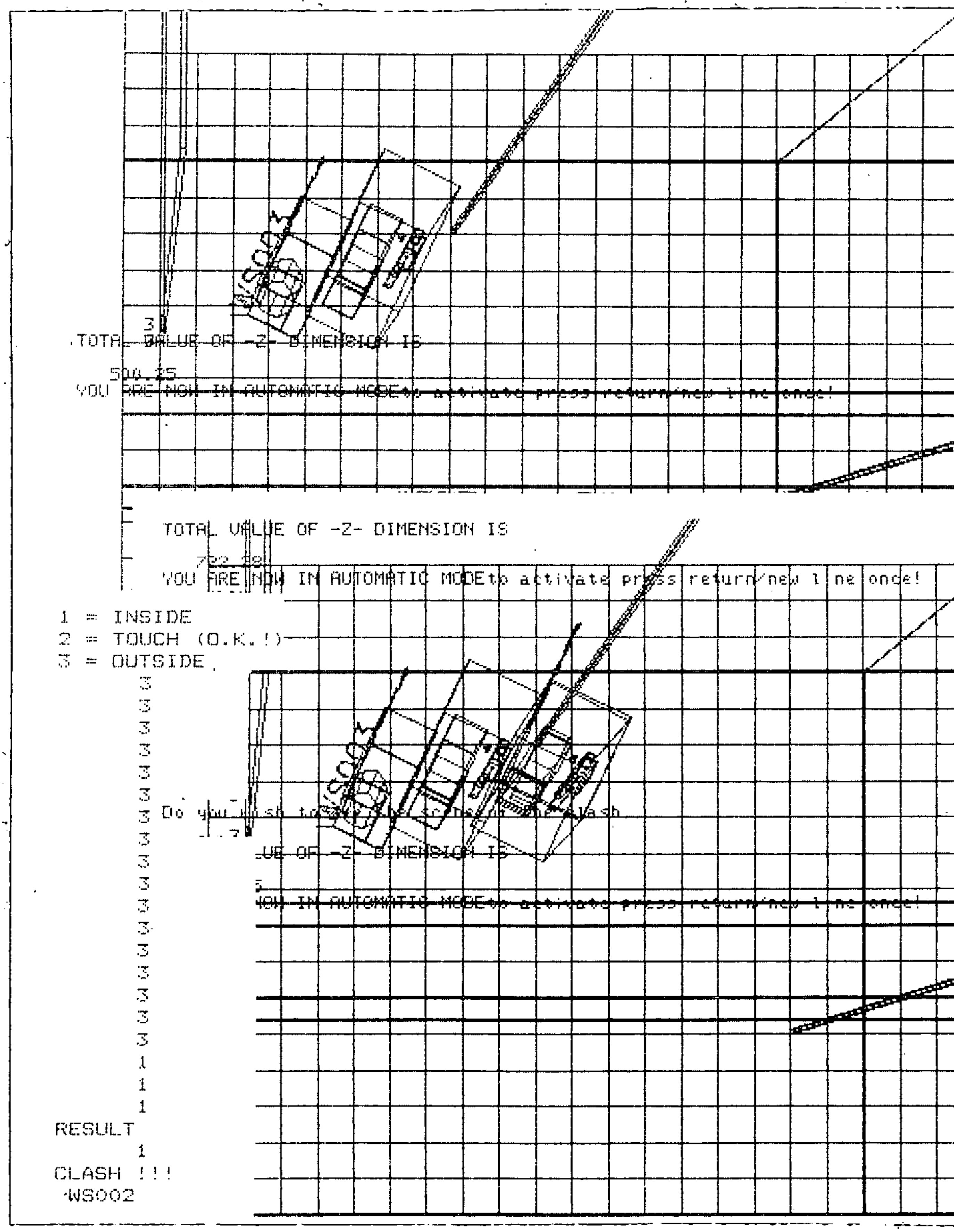

TOTAL VALUE OF -Z- DIMENSION IS
YOU ARE NOW IN AUTOMATIC MODEto activate press return/new line once!
1 = INSIDE
2 = TOUCH (O.K.!)
3 = OUTSIDE
3
3
3
3
3
3
3
3
3
3
3
3
3
3
3
3
3
1
1
1
RESULT
1
CLASH !!!
WS002

Fig. 18.

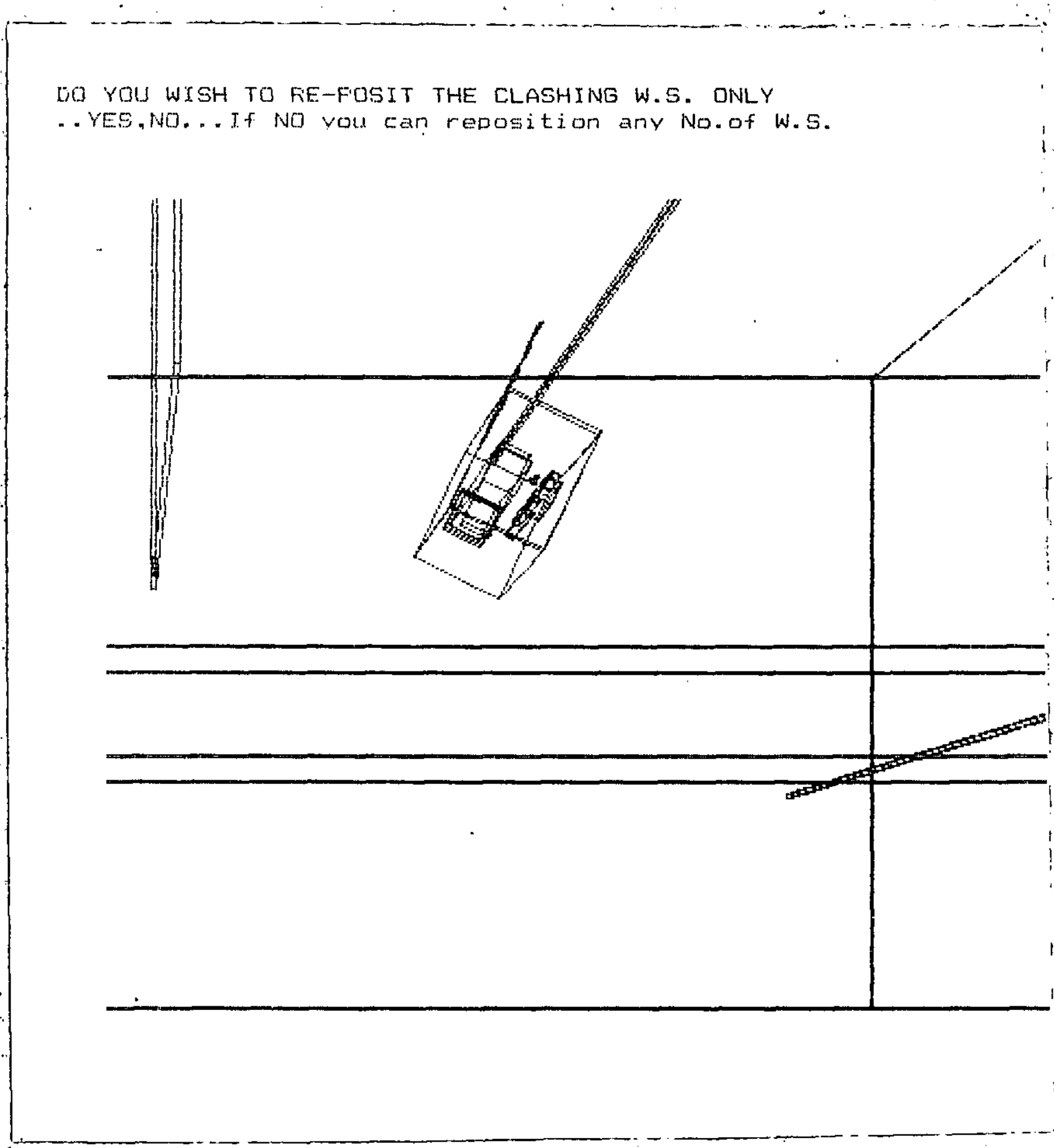
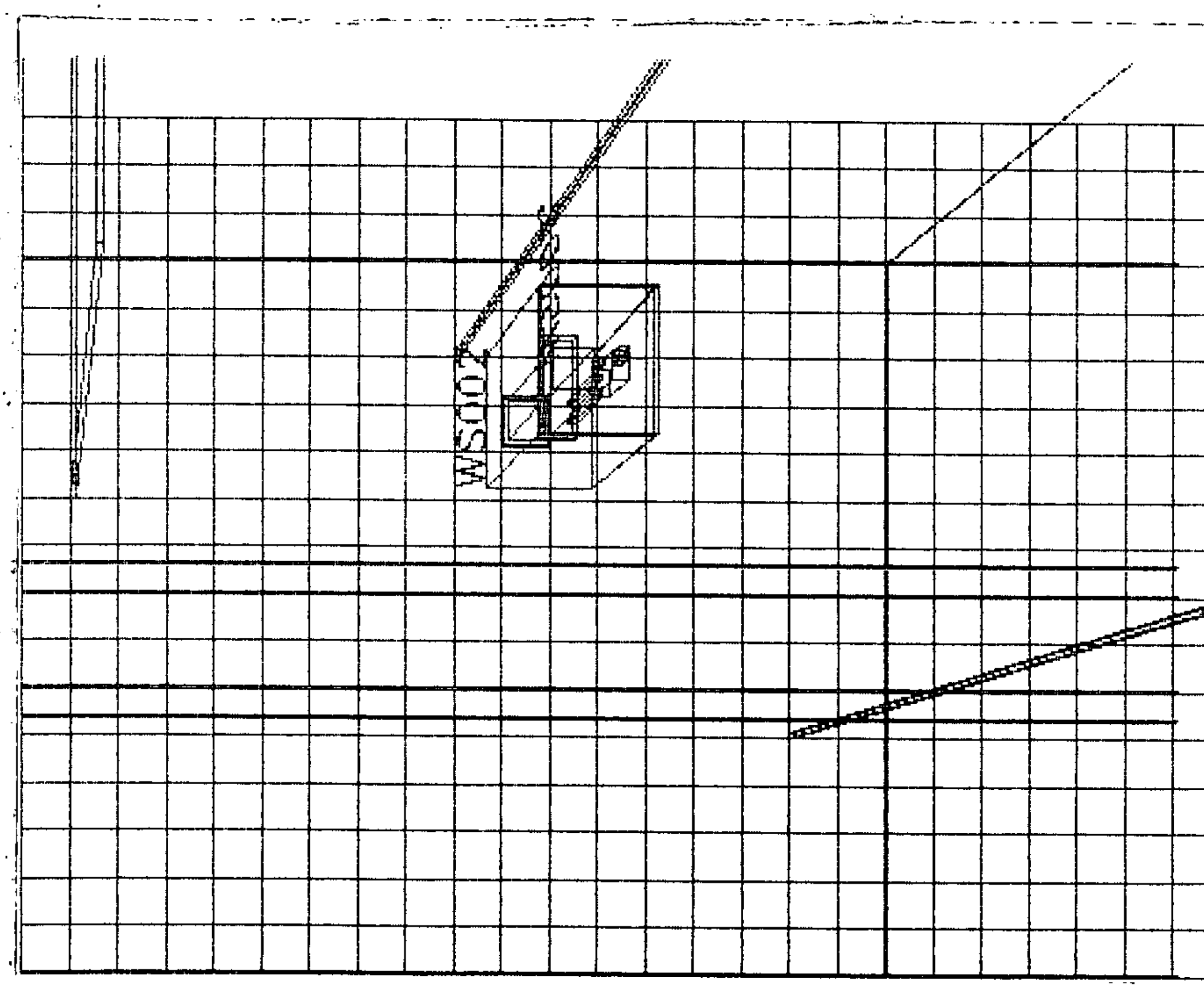

DO YOU WISH TO RE-POSIT THE CLASHING W.S. ONLY
..YES,NO...If NO you can reposition any No.of W.S.

Fig. 19.

You are now in the Manual ..to..Auto Mode

Do you wish to re-POSITion the Work Station...YE or NO



Please POSITion the W.S. by cross-hairs...
Is the POSITion of W.S. according to your wish...YE or NO

Fig. 20. a)

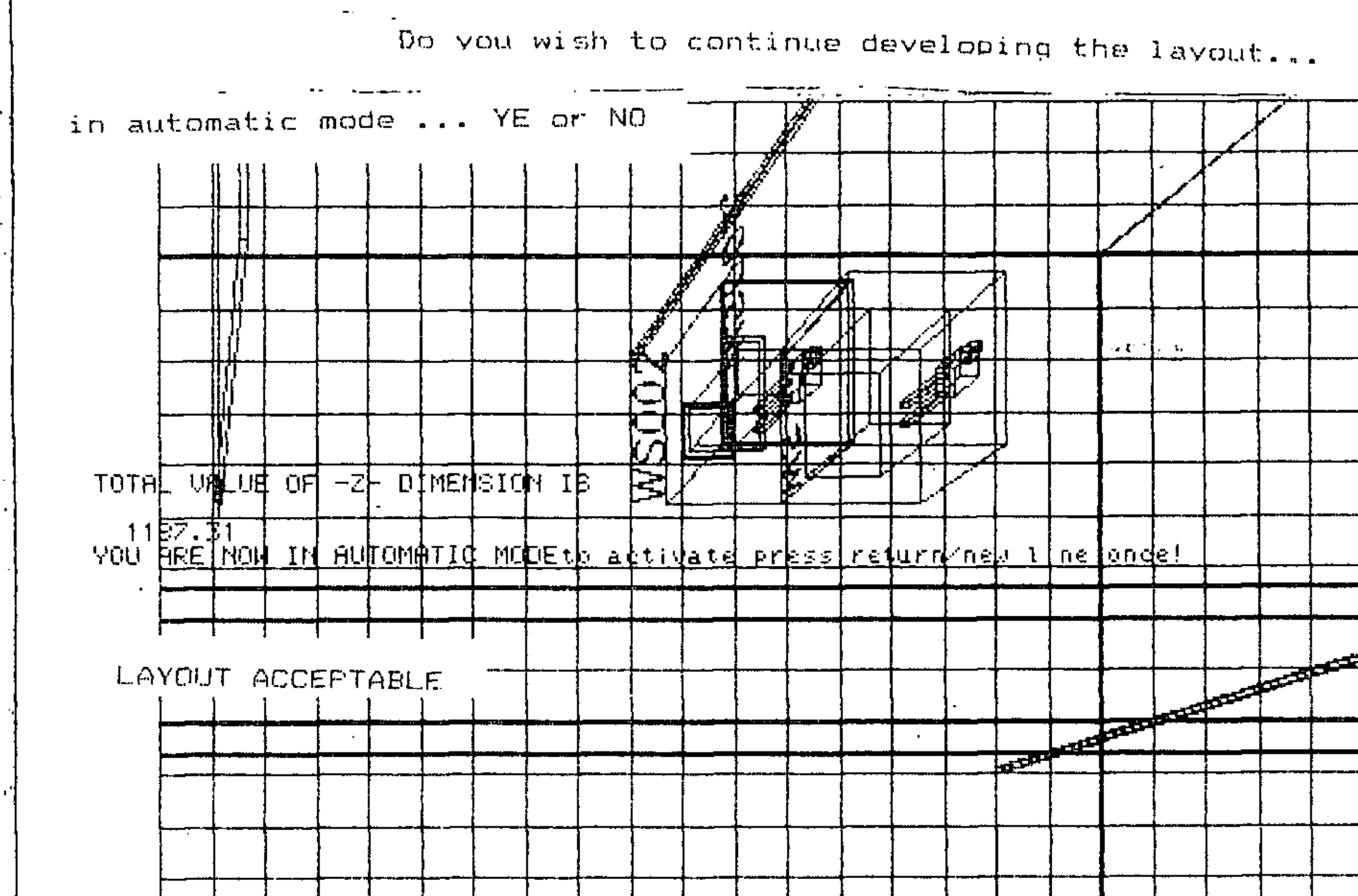
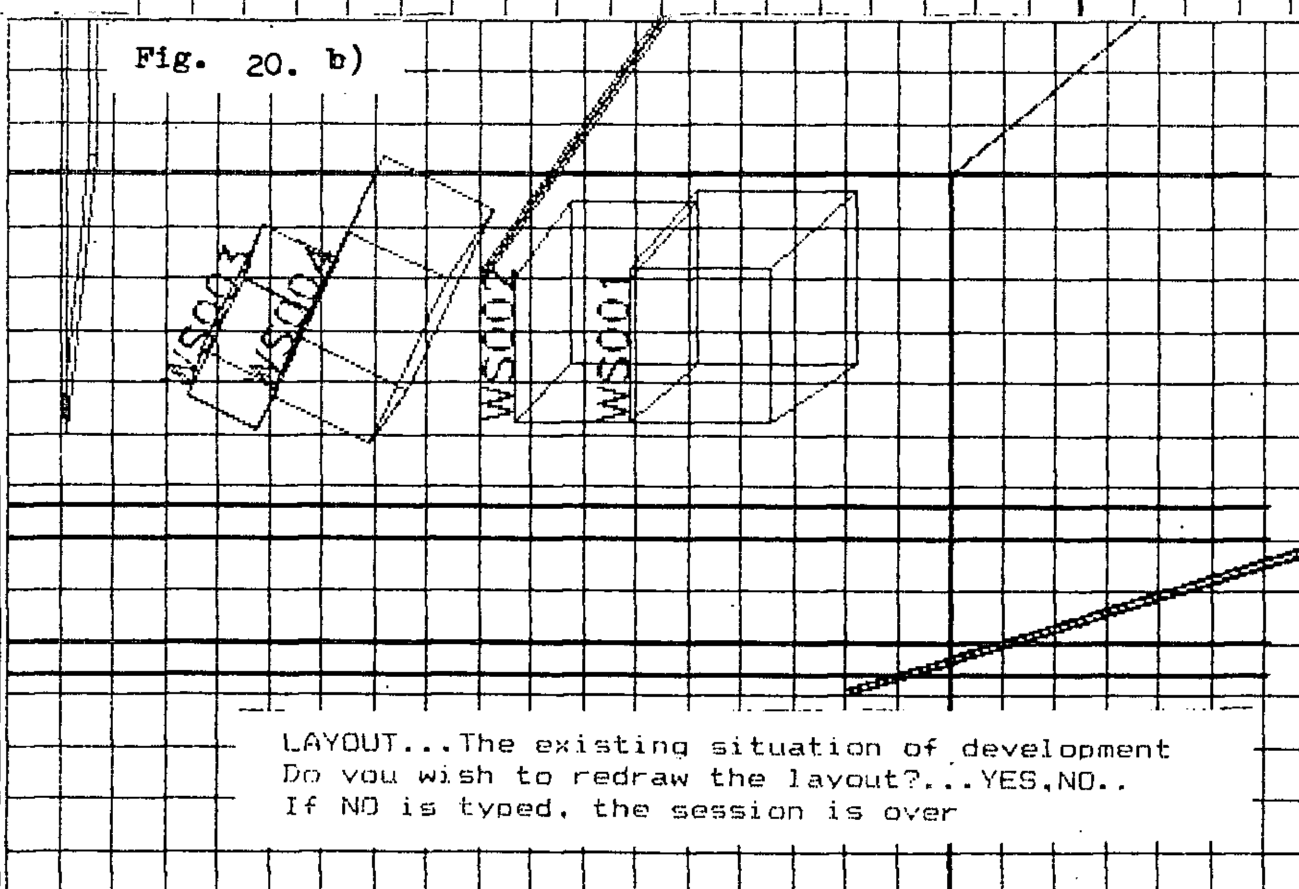


Fig. 20. b)



4.5.5 DISPLAY PROGRAM

Program 'DISPLAY.FOR' has been compiled for displaying the layout and manipulation of the whole scene. It also allows the user to study developed alternatives, and provides a better 3-D presentation on VDU and/or printing.
The user feeds in a requested distance, rotation, and elevation, and the layout is shown on VDU {see Fig.21.}.

ENLARGEMENT OF THE SCENE

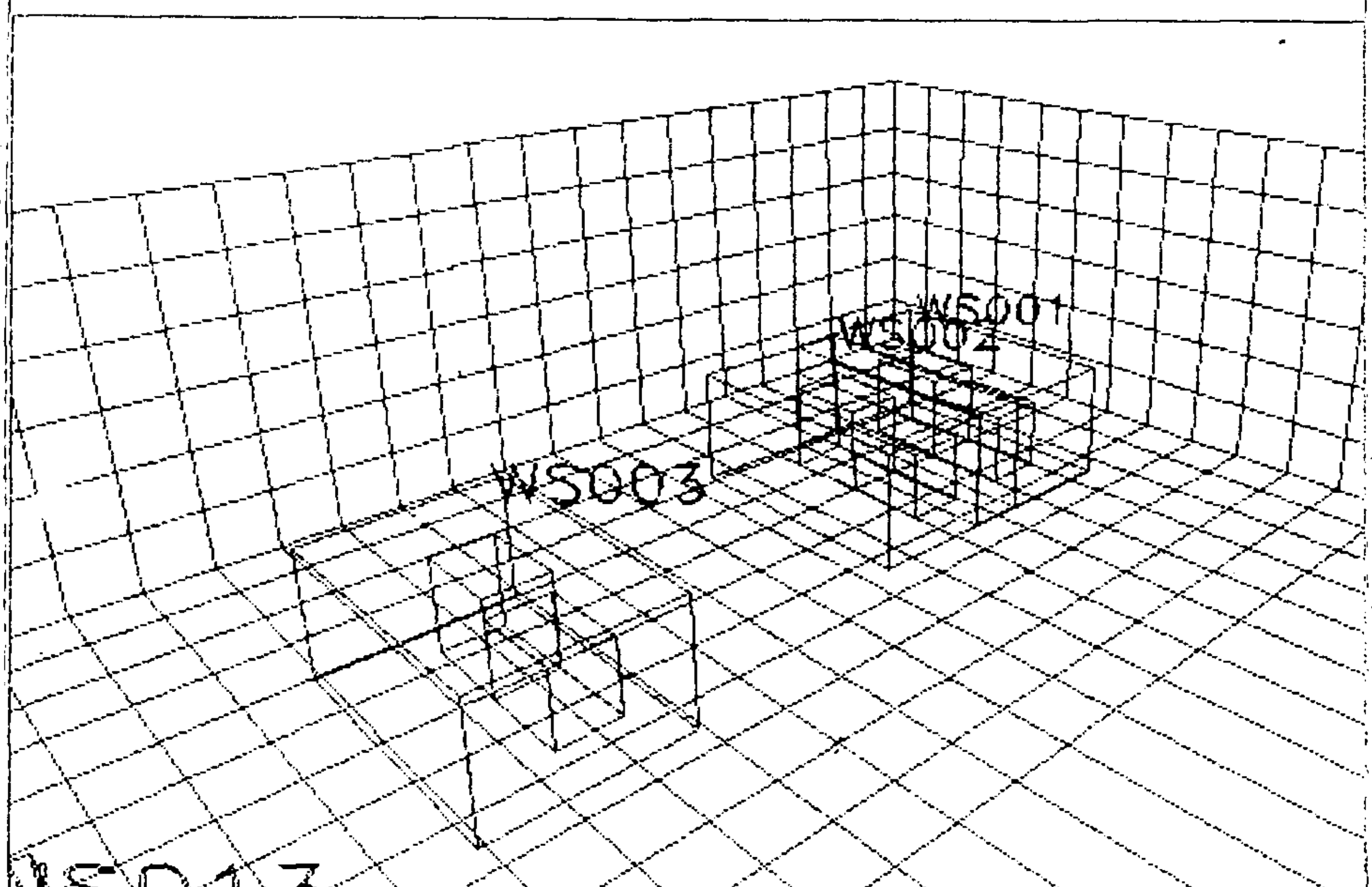


Fig. 21.
RESULT OF 'DISPLAYO' PROGRAM

4.5.6 AUXILIARY PROGRAMS

To simulate real situations in Factory Layout Planning some Auxiliary Programs have been compiled:

4.5.6.1 MANUAL FEEDING OF WORK STATIONS

Frequently, in practice, the plant layout engineer has a list of work stations available for the manufacturing programme. From the list, suitable machine tools and equipment must be selected and a 'technological' order of their relative positions in the layout has to be established. Interrelations of these operations is illustrated by Fig.22. Programs for 'technological' positioning developed at Strathclyde University (Dr.Carrie [13,14]), were originally intended to be used here. However, because of some technical difficulties experienced in the transfer of the Strathclyde programs, the program 'MFEED.FOR' was compiled instead. The program is substituting the results of Dr.Carrie's programs and feeds in a ready designed 'technological' line of work stations needed for the job. The program allows the user to change the 'technological' order, with changing requirements.

To accompany 'MFEED.FOR', program 'WSVTOTO.FOR' was written, which allows the reorganisation of Work Station Modules (in 'largest volume' presentation, see Fig. 5.), according to 'technological' order. This step was found necessary because the 'largest volumes' of Work Station Modules are only used in some parts of programs, while in other parts the detailed Work Station Modules are used. The 'largest volumes' give a clearer presentation and understanding of layout development {see Fig. 20.b)}, while layouts using detailed Work Station Modules may be used for detailed study or final placement of machines (anchoring bolts,etc.) on shop floor.

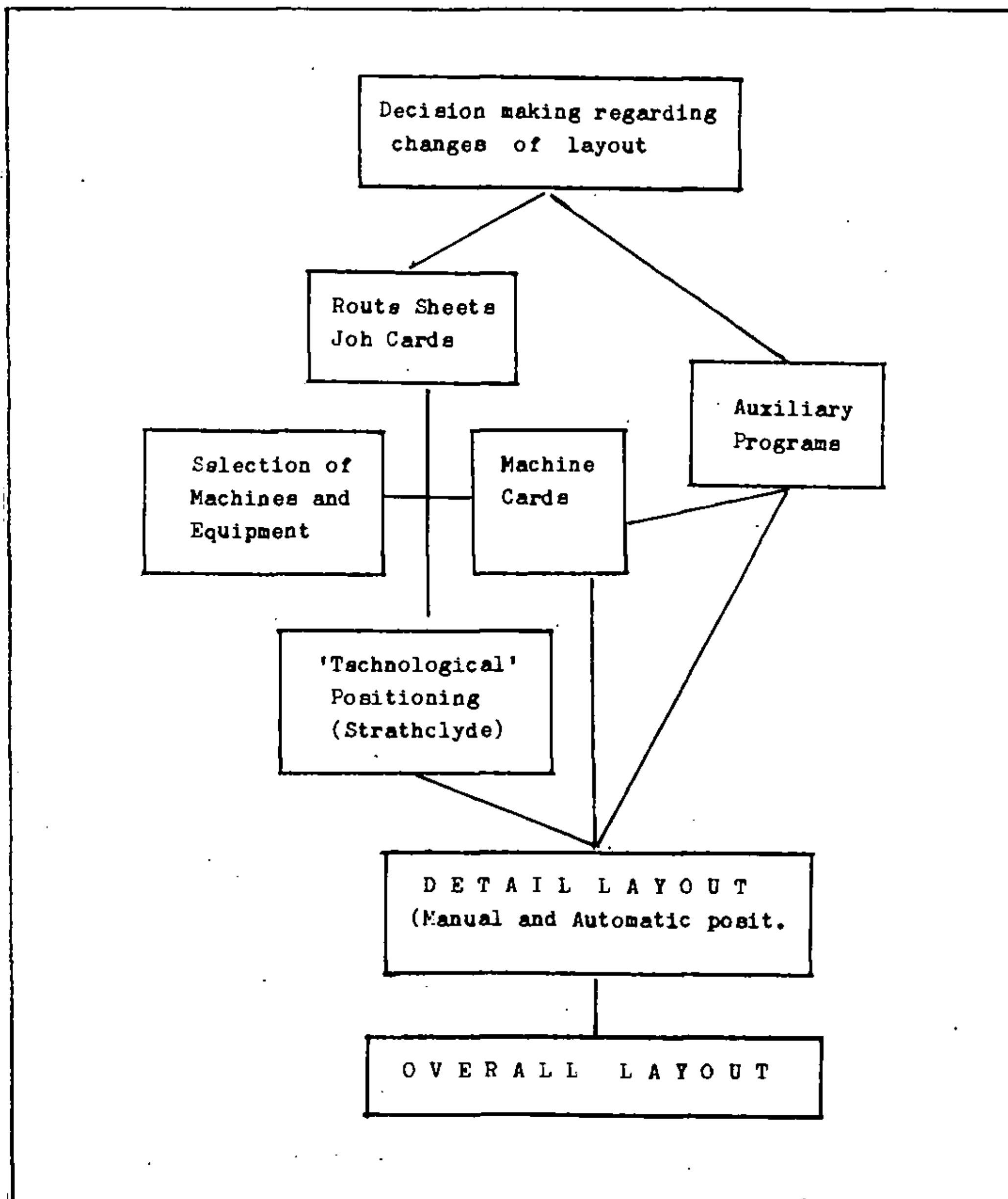


Fig. 22. T O T A L CAFLAP SYSTEM

4.5.6.2 CAPACITY CALCULATIONS

The layout engineer must of course be in possession of some basic figures about the new layout (see Chapter 2. Project stages 1. and 2.). The capacity calculation program 'M100.FOR' is intended for basic capacity calculations for the case where no detailed information about production is available.
The program provides calculation of:

- Volume of Material Handling;
- Number of work stations needed;
- Manufacturing area needed;
- Total length of industrial bay.

This program is an example of others which may be developed in the future to estimate and plan, e.g. manning levels, production capacity in relation to shift coeficient, general effectivnes of layout, etc..

5. THE TESTING OF PROGRAMS

All programs were running and were tested for required functions.

5.1 'WSBUILDR.FOR' Program

To produce a 3-D template of an average Work Station Module takes 10-15 minutes. The template gives a reasonable image of the work station and, even if positioned on a one meter grid, it was found that it could be used for the placement of machines within the usual shop floor tolerances of 10 cm.

The 'WSRECALL.FOR' program retrieves the filed 3-D template.

5.2 BUILDING 'CIVES3.FOR' Design Program

To place any civil engineering element via this program takes about 30 to 60 seconds, and any change could be introduced equally fast. The 3-D model of the interior of the bay produced gives a good image of the space available for the layout. The capacity of maximum 200 building elements is more than sufficient.

5.3 MANUAL POSITIONING PROGRAMS

These programs were most thoroughly tested and no special problems were encountered by users. The positioning of objects was found to be very fast and easy procedure. The only disadvantage is the inaccuracy that arise in connection with the use of joystick. Due to that, incompatible pictures on VDU and printouts are produced, if an adjacent position of work stations is intended. The printout from the CALCOMP 960 plotter shows a double line where work stations touch, while the optical reading of crosshair/work station on VDU gives a single image. This is evidently caused by a combination of both hardware deficiency and the human factor error.

5.4 AUTOMATIC POSITIONING PROGRAM

The composite program 'POSCLASH5.FOR' was found to be easy to use and produced very fast automatic positioning of Work Station Modules according to the design specification.

When ever a clash with building elements occurs, the collision course finding is immediate and the manual override can start without any delay.

Similar problems to those mentioned in the last section have been found with the joystick position accuracy.

IDENTIFICATION BY TAG NOS:

The Tag Number of the 'largest volume' of work station is placed horizontally at the base plate level; while the tag number of the detailed Work Station Module is written vertically in an upright position. This design is a result of the findings during the testing of 'DISPLAY.FOR' Programs, and makes the reading of Tag No. easier in any display position.

5.5 DISPLAY PROGRAM

'DISPLAY.FOR' program ran without any problems, and the device for observation of the scene from any angle and distance proved useful.

6. DISCUSSION OF RESULTS

The use of PICASO for 3-D design and simulation has proved to be very useful. PICASO is a unique 2-D and 3-D computer graphics system developed at Middlesex Polytechnic to symplify the human interface when manipulating shapes and objects. As with any software environment there are limitations imposed upon the user when using the available commands. CAFLAP's interface would have been greatly improved if the user had had control over line types when objects were subject to hidden-line removal. Objects would have looked tidier if their surfaces could have been shaded or even transparent; there was a need to move elements around the screen in real-time. These problems are not identified as specific criticisms of PICASO but rather to identify the type of graphics facilities CAFLAP could benefit from in future with access to a sophisticated real-time full-colour graphics workstation.

It is felt that the drawing of work stations or buildings by use of a joystick should be attempted in future development of CAFLAP, despite the knowledge of possible inaccuracies inherent in the joystick-VDU-printer combination.

Experience has shown that accuracy, using a scale of 1:50 and a layout grid of 250x250 mm, is satisfactory for the needs of any type of layout for any type of mechanical engineering production; so inaccuracies resulting from use of joystick are within usual plant layout design tolerance (10cm).

The interactive program 'IYTVAX00.FOR' for manual positioning has all positive functions specified, and it is believed that it could be used for any plant layout almost universally. Small adaptations, for example the listing of Work Stations or, vice versa, printing Work Station lists not only in chronological but also in the 'technological' order, could easily be made on request. The same is true for the 'IYTWSFILE.FOR'program.

Athough the 'POSCLASH5.FOR' Program is the most developed program of all, it has scope for further development as a more versatile tool. For example, collision course finding could be extended (on the principles already developed) for clashes of work station foundations with underground piping or power ducts network, etc.. Similarly, principles for positioning according to Fig.7. a) and b), could be applied to layouts such as Fig.7. c) etc.. This could spare present users possible errors with a negative reading of joystick. However, selfguarding mechanism, protecting user against the error during manipulation (negative angles), would be useful to add.

During the automatic positioning, with the hardware used here and system of identification of spaces (no hatching, no tinting), the Maintenance Space cannot be placed in the Man-Space of the previous work station to increase the shop floor utilisation. This has to be considered as a calculated loss at this stage of development.

BENEFITS OF CAFLAP TO THE PLANT LAYOUT ENGINEER.

CAFLAP programs testing showed there are two main areas of benefits for the user:
Firstly, it makes plant layout work easier, and the task is accomplished faster.

Secondly, CAFLAP functions as a methodological tool, guiding the user to perform the plant layout tasks systematically and with a holistic approach. This improves the quality of the work and and expands user's potential, leading towards a deeper understanding of the nature of plant layout problems. CAFLAP stimulates the user's creativity, giving an opportunity actually to override the computer when necessary. The user is thus the master of the computer, not just its follower. This is illustrated in Fig.23, which shows how CAFLAP benefits the plant layout engineer.

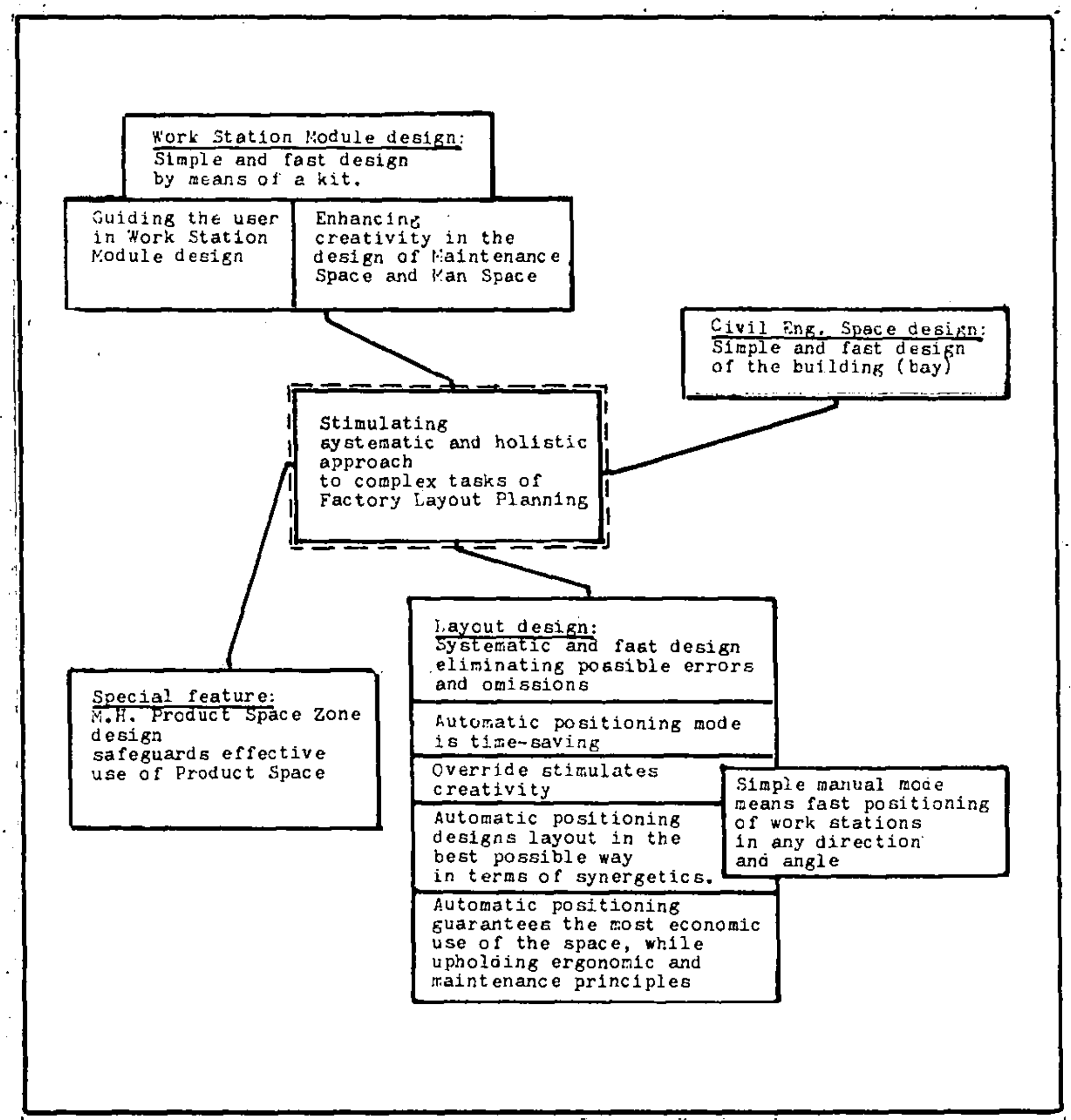


Fig. 23. THE MAIN BENEFITS OF CAFLAP TO THE PLANT LAYOUT ENGINEER

7. INDUSTRIAL APPLICATION OF CAFLAP

The interactive program for manual positioning was used during 1986-87 Factory Layout Planning projects for Eltron (London) Ltd. Eltron (London) Ltd., established in 1927, has three factories employing over 200 people and is one of the world's leading manufacturers of industrial electrical heating systems and equipment.

Eltron required new layouts for a two-fold increase of production capacity on 'green field' site, and cooperated with Middlesex Polytechnic on development of necessary layouts. For examples see Appendix III., Drawings No. 2. and 3.

Although it was not possible to do any detailed and exact quantitative control-study evaluation, work on the layout using CAFLAP proved much faster than had been possible hitherto by traditional methods.

Final results, with drawings printed on the CALCOMP 960 plotter, were also of a superior quality to those previously obtained. The results produced were more than satisfactory in fulfilling the practical needs of the production management team. Certainly if detail Work Stations Modules had also been incorporated at that time, the result would have been even more remarkable and well received by

Industry.

The automatic positioning program was also not then fully developed so that it was not possible to test its impact in a real industrial environment. However, test runs have shown that the method of automatic positioning of individual work station 3-D templates in construction or improvement situations, with the use of collision course finding and clash indication, is viable and very fast. Originally, as stated in chapter 4.2, the development of CAFLAP was aimed at layout and relayout of a medium size engineering company with batch production and with a maximum product weight of 60kN. These limits were set because the development of CAFLAP was targeted on companies with limited resources, premises, and manufacturing facilities. It was originally wrongly contemplated that the span of an industrial bay, or the type of M.H. equipment (e.g. cranes, fork lift trucks, conveyors) and shape of aisles, could limit the use of CAFLAP automated layout system. These factors could be restrictive and could cause problems for the use of computerised methods designing block plan plant layout (Chapter 3.2). But the CAFLAP method of positioning individual work stations in a 'technological' line is not restricted in this way. Hence the advanced development of the automated positioning method has actually disproved the existence of such a restriction, and CAFLAP may be used for any general application.

EVALUATION OF PROJECT ALTERNATIVES

Projects and alternatives, in a classical plant layout approach, are usually evaluated by means of comparison of the following main parameters:

- production programme per time unit (expressed in terms of quantity of products, weight, etc.)
- areas
- number of production machines
- number of operators

and indicators derived from the above e.g:

Ratio of Manufacturing Area to Total Area;
Area per one work station (in m sq./ 1);
Production output per 1 m sq. of Manufacturing Area (kN /m sq.) etc.

The Space Management concept offers a completely new approach to the economic evaluation of projects and their alternatives, giving more accurate results. This is achieved by considering new facts, established in the course of this research work, with following examples of resulting indicators e.g.:

Ratio of :

Manufacturing Space to total space of the hall;

Manufacturing Space to Product Space;

Manufacturing Space to Maintenance Space;

Manufacturing Space + Product Space to Manufacturing Services Space;

Manufacturing + Product + Manufacturing Services Spaces to 'Breathing Space'... etc.

The highest ratio of Manufacturing Space to the 'other' spaces is sought. A set of indicators may be tailored according to individual needs.
They could also provide a very instructive feedback for designers and machine manufacturers.

8. PRESENT LIMITATIONS OF THE SYSTEM AND RECOMMENDATIONS FOR FURTHER DEVELOPMENT

At this stage of development the system has the following limitations:

There is no independent facility for collision course finding for travelling overhead cranes or installed robots. If they are to be avoided, the 'obstacles' have to be entered at present via 'CIVES3.FOR' program. In the same way that power and pipeline networks are considered.

A facility for an automatic design for an width of industrial bay and optimum industrial hall is not yet available.

There is as yet no facility to move the picture of the bay to keep pace with automatic development of the layout, and to produce the 'continuous bay' in graphical presentation. At present the area of layout shown is limited to individual sections, determined by the size of VDU.

Other programs (e.g. Strathclyde) desirable for 'technological' positioning of work stations are not incorporated in the overall system.

With respect to the above limitations, the following are areas for further development:

- to extend the already developed programs into all the remaining areas of plant layout;
- to use colours (colour VDU) for further improvement of identification of spaces (man, maintenance) and for space saving during collision course finding;
- to add a facility for complete automatic design of industrial bays and halls;
- to incorporate the 'technological' positioning programs and facility for automatic retrieving of information from Work Station Cards;
- to build a library of Work Station Modules of all British made machine tools;
- to incorporate/develop the system into a Computer Integrated Engineering System.

9. CONCLUSIONS

A Computer Aided Factory Layout Planning system has been developed to the stage where it is industrially useful: further refinements are suggested.

The SPACE MANAGEMENT principles used are abstracted from the complex reality of the Factory Layout Planning field. These principles, translated into CAFLAP system, enable layout tasks to be greatly simplified.

All the main ideas and principles of CAFLAP developed here have been confirmed by computer programs compiled and their results.

The Computer Aided Factory Layout Planning system should not be considered as a new drafting system, nor as an algorithm for finding the most suitable relative placement of work stations.

CAFLAP should be judged as a tool for:

- speeding up layout work through the application of CAFLAP ideas e.g. Work Station Modules, Space Management concepts and positioning systems;
- increasing the quality of layout work by means of design of Work Station Modules and

collision course finding·positioning programs;

- diminishing manual repetitivenes of layout work;
- introducing facility for a more detailed layout in the early stages of a project, which will increase the quality and the quantity of information available for strategic decision making.

CAFLAP is therefore a device to:

- free engineers for more creative work;
- eliminate the number of project stages;
- ease finding optimum alternatives of layout;
- introduce new models into production in the shortest possible time;
- lower the cost of capital investment.

The developed SPACE MANAGEMENT concept also offers a new approach to the economic evaluation of projects and their alternatives, by means of comparison of ratios of spaces (Chapter 7. -Economic Evaluation of Project Alternatives). Assessment of the essential Manufacturing Spaces, together with all the auxiliary, service, and 'breathing' spaces, helps to find the areas of potential retrench. This then leads to an expedient relayout and even to a rational redesign of Work Station Modules. If an improvement of the existing factory is undertaken, the assessment, with the help of the spaces ratios, pinpoints the areas with the most abundant use of the auxiliary spaces which should be tackled first.

Computer graphics methodology, principles, and kinetic functions, have all been used in an innovative way to assist the creative design work of plant layout engineer.

An early decision was made to use simple hardware in this work, e.g. a small monochrome VDU and a basic printer. The aim was to make CAFLAP system accessible to a widest possible spectrum of users. Certainly this decision imposed some limitations on the extent of development of the Space Management ideas. Further development is therefore a matter of some compromise, but the main objectives of the current work have been achieved.

CAFLAP system is an important step forward in the direction of total computer integrated engineering system design.

BOB KOBLIHA

22nd July 1988.

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The key words were: Plant Layout, Factory Layout, Computer Aided and CAD.

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APPENDIX I

Appendix I

TERMINOLOGY

Standard terminology, given by British Standards, still fails to cover some areas in Production and Industrial Engineering. In these areas terminology varies from factory to factory and also internationally among English speaking countries. This is true especially in the field of Factory Layout Planning which is often accented by American English. Some terminology and expressions which, are frequently used in parallel, follow:

Item	Term	Parallel Expression(s)	Remarks
1	Plant Layout	Factory Layout Planning Facility Layout Facility Allocation Economic Activity Location	
2	Project Stage	Project Phase	e.g. Muther[4]
3	Feasibility Study	Programme Study Investment Study	
4	Investment Project	Programme Tender	e.g.Ford Motor Company
5	Project	Final Stage Project	

6	Working Drawings	Detail Drawings Shop Drawings "as made" drawings	
7	Introductory Project		intermediate stage
8	'technological' positioning	theoretical pos.	positioning to suit best technol. demands and economy of production
9	Preventive Maintenance	Regular Maintenance	
10	Manufacturing Services	Auxiliary Services Subsidiary Services	
11	Services	Energy supply	
12	Templates on 'Skins'	Templates and Tapes	Tompkins and White[39]
		Templates and Paste	Farish[33]

APPENDIX II

C O M P U T E R   P R O G R A M S

1. 'WSBUILDR.FOR'
2. 'WSRECALL.FOR'
3. 'CIVES.FOR'
4. 'IYTVAX00.FOR'
5. 'IYTWSFILE.FOR'
6. 'POSCLASH5.FOR'
7. 'DISPLAY.FOR'
8. 'MFEED.FOR'
9. 'WSVTOTO.FOR'
10. 'M100.FOR'

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          BB      BB    00      00   BB      BB      11
          BB      BB    00      00   BB      BB      11
          BB      BB    00      00   BB      BB      11
          BBBBBBBB        000000     BBBBBBBB      111111
          BBBBBBBB        000000     BBBBBBBB      111111

      W   W   SSSS   BBBB   U   U   111   L       DDDD   RRRR
      W   W  S       B   B  U   U    I    L       D   D  R   R
      W   W  S       B   B  U   U    I    L       D   D  R   R
      W   W   SSS    BBBB   U   U    I    L       D   D  RRRR
      W W W      S   B   B  U   U    I    L       D   D  R R
      WW WW      S   B   B  U   U    I    L       D   D  R  R
      W   W  SSSS    BBBB   UUUUU   111   LLLLL   DDDD   R   R

          J   OOO   BBBB         1      1    55555   999
          J  O   O  B   B       11     11    5      9   9
          J  O   O  B   B        1      1    555    9   9
          J  O   O  BBBB         1      1       5    9999
      J   J  O   O  B   B        1      1       5       9
      J   J  O   O  B   B        1      1    5  5       9
       JJJ    OOO   BBBB        111    111    555    999

(1159) Queued to SYS$PRINT on 9-NOV-1987 12:13 by user BOB1, UIC [RESM0012,BOB1], under account RES
on printer _LPA0: on 9-NOV-1987 12:13 from queue LPA0.

44444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444
4444444444444444444444  Digital Equipment Corporation - VAX/VMS Version V4.5  444444444444444444
44444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444444
```

```
C      "WSBUILDR.FOR" PROGRAM
C      FOR DESIGN/DRAWING OF WORK STATIONS AND EQUIPM...
C      IMPROVED ON 1-6.10.86.
C      FURTHER IMPROVEMENT INTRODUCED ON 10.2.87.
C      FURTHER IMPROVEMENT ON 31.7.87 ('OPERATOR' ADDED)
C

       REAL A(3000),B(5000),C(5000),R(2000)
       INTEGER SIDES
       LOGICAL FIRST
       CHARACTER*12 FILNAM
       CHARACTER*12 WSNAME
       CHARACTER*12 TAGNO


       FIRST = .TRUE.
C
C
       WRITE (6,50)
50     FORMAT (' WORK STATION DESIGN PROGRAM. ')
C      Please start
C      &design from the origin using only positive figures ...
C      &including Work Station Module Volume...turning point is
C      &left bottom corner. This is important for Joystick and
C      &automatic positioning as well!
       CALL BELL
       CALL NEWPAG

       WRITE (6,60)
60     FORMAT (' SHAPES and  CODES'//' Select wanted')
       CALL OPDISC (FILNAM,10)

30     CONTINUE
       WRITE (6,5001)
5001   FORMAT (' BX   BOX_shaped PARTS,start with foundat.plate')
       WRITE (6,5020)
5020   FORMAT (' AB   ANCHORING BOLTS or FOUNDATION BOLTS')
       WRITE (6,5030)
5030   FORMAT (' CY   CYLINDRICAL PARTS')
       WRITE (6,5040)
5040   FORMAT (' CO   CONICAL PARTS')
       WRITE (6,5050)
5050   FORMAT (' PY   PYRAMIDAL PARTS')
       WRITE  (6,5060)
5060   FORMAT (' SP   SPHERICAL PARTS')
       WRITE (6,5090)
5090   FORMAT (' OP   OPERATOR')
       WRITE (6,5070)
5070   FORMAT (' TN   TAG NUMBER a unique identification no')
       WRITE (6,5080)
5080   FORMAT (' XX   NO MORE SHAPES REQUESTED-END OF SESSION',/)
       WRITE (6,35)
35     FORMAT (' Please write the selected CODE')
       CALL BELL

       READ(5,40)CODE
40     FORMAT(A2/)
       IF (CODE.EQ.'BX') GOTO 200
       IF (CODE.EQ.'AB') GOTO 300
       IF (CODE.EQ.'CY') GOTO 400
```

```
      IF (CODE.EQ.'CO') GOTO 500
      IF (CODE.EQ.'PY') GOTO 600
      IF (CODE.EQ.'SP') GOTO 700
      IF (CODE.EQ.'UP') GOTO 900
      IF (CODE.EQ.'IN') GOTO 800
      IF (CODE.EQ.'XX') GOTO 100
C
C     IF THE ENTRY DOES NOT CORRESPOND WITH THE CODE
C     THE ERROR MESSAGE IS WRITTEN
C
      CALL BELL

      WRITE (6,70)
70    FORMAT (' Please enter your response again - using CAPITALS')
      GOTO 30

200   CONTINUE
C
C     BOX SHAPES ARE INTRODUCED
C
      CALL BELL
      WRITE (6,210)
210   FORMAT (' Please enter dim. for X,Y,Z,ROT,XS,YS,ZS in cm!'/)
C
C     NOTE DIMENSIONS MUST BE PUT IN CENTIMETERS
C     NUMBERS MUST BE ENTERED  IN 5 FIG.,DEC.POIN AND 2 FIG.FORM
C     ROTATION IN DEGREE (EXAMPLE 30.0)
C
      READ (5,220,END=230) X,Y,Z,ROT,XS,YS,ZS
      WRITE (10,220) X,Y,Z,ROT,XS,YS,ZS
220   FORMAT (7F8.2/)
      CALL BOX (A,X,Y,Z)
      CALL TURN3D (A,ROT,0.0,0.0,2,B)
      CALL SHIFT3 (B,XS,YS,ZS)
230   CONTINUE
      GOTO 1000

300   CONTINUE
      CALL BELL
C
C     SHAPES OF ENCHORING BOLTS ARE INTRODUCED
C

      WRITE(6,310)
310   FORMAT (' Please enter data for ROTation and Shift XS,YS,ZS'/)
      READ(5,320,END=330)ROT,XS,YS,ZS
      WRITE(10,320)ROT,XS,YS,ZS
320   FORMAT(4F8.2/)
      CALL FBOLT (A)
      CALL TURN3D(A,ROT,0.0,0.0,2,B)
      CALL SHIFT3(B,XS,YS,ZS)
330   CONTINUE
      GOTO 1000

400   CONTINUE
      CALL BELL
C
C     CYLINDRICAL PARTS ARE INTRODUCED
C
      WRITE(6,405)
```

```
405   FORMAT(' Please write dim. DIA,HEIGHT,SIDES,ROT,XS,YS,ZS'/)

      READ (5,410,END=420)DIA,HEIG,SIDES,ROT,XS,YS,ZS
      WRITE(10,410)DIA,HEIG,SIDES,ROT,XS,YS,ZS
410   FORMAT(2F8.2,I8,4F8.2)
      CALL CYLIND(A,DIA,HEIG,SIDES)
      CALL TURN3D(A,ROT,0.0,0.0,2,B)
      CALL SHIFT3(B,XS,YS,ZS)
420   CONTINUE
      GOTO 1000


500   CONTINUE
      CALL BELL
C
C     CONICAL PARTS ARE INTRODUCED HERE
C
      WRITE (6,510)
510   FORMAT (' Please enter dim. of cone DIAM,HEIGHT and No of
     &sides,Rotation ROT and shift XS,YS,ZS'//)
      READ (5,520,END=530)DIAM,HEIGHT,NO,ROT,XS,YS,ZS
      WRITE (10,520) DIAM,HEIGHT,NO,ROT,XS,YS,ZS
520   FORMAT (2F8.2,I14,4F8.2)
      CALL CONE (A,DIAM,HEIGHT,NO)
      CALL TURN3D (A,ROT,0.0,0.0,2,B)
      CALL SHIFT3 (B,XS,YS,ZS)
530   CONTINUE
      GOTO 1000
C
600   CONTINUE
      CALL BELL
C
C     PYRAMIDAL PARTS ARE INTRODUCED HERE
C
      WRITE(6,610)
610   FORMAT (' Please enter dimensions for Pyramidal parts WIDTH,
     &DEPTH,HEIGHT and ROTATION and Shift XS,YS,ZS'//)
      READ (5,620,END=630) WIDTH,DEPTH,HEIGHT,ROT,XS,YS,ZS
      WRITE (10,620) WIDTH,DEPTH,HEIGHT,ROT,XS,YS,ZS
620   FORMAT (7F8.2)
      CALL PYRAM (A,WIDTH,DEPTH,HEIGHT)
      CALL TURN3D (A,ROT,0.0,0.0,2,B)
      CALL SHIFT3 (B,XS,YS,ZS)
630   CONTINUE
      GOTO 1000


700   CONTINUE
      CALL BELL

C
C     HERE ARE INTRODUCED ALL SPHERICAL PARTS
C
      WRITE (6,710)
710   FORMAT (' Please enter dimension for spherical parts DIAM,
     &NH_no of horizontal tiles and NV_no of vertical tiles
     &and ROTation and Shift XS,YS,ZS'/)


      READ (5,720,END=730)DIAM,NH,NV,ROT,XS,YS,ZS
```

```
      WRITE (10,720)DIAM,NH,NV,ROT,XS,YS,ZS
720   FORMAT (1F8.2,2I8,4F8.2)
      CALL SPHERE (A,DIAM,NH,NV)
      CALL TURN3D(A,ROT,0.0,0.0,2,B)
      CALL SHIFT3(B,XS,YS,ZS)
730   CONTINUE
      GOTO 1000

900   CONTINUE
      CALL BELL
C
C     3-D TEMPLATE/MODEL OF 'OPERATOR' IS INTRODUCED
C
      WRITE (6,910)
910   FORMAT (' Please enter data for ROTATION and SHIFT...
     &XS,YS,ZS' /)
      READ (5,920,END=930)ROT,XS,YS,ZS
      WRITE (10,920)ROT,XS,YS,ZS
920   FORMAT (4F8.2)
      CALL OPERATOR (A)
      CALL TURN3D (A,ROT,0.0,0.0,2,B)
      CALL SHIFT3 (B,XS,YS,ZS)
930   CONTINUE
      GOTO 1000

800   CONTINUE
      CALL BELL
C
C     HERE IS INTRODUCED A TAG NUMBER
C
      WRITE (6,810)
810   FORMAT (' Please enter TAG NO, ROTation and shift XS,YS,ZS'/)
      READ (5,820,END=830)TAGNO,ROT,XS,YS,ZS
      WRITE(10,820)TAGNO,ROT,XS,YS,ZS
820   FORMAT(A6,4F8.2)
      CALL HERSH(TAGNO,6,2,60.0,R)
      CALL TRANSP(R,A)
      CALL TURN3D (A,ROT,0.0,0.0,2,B)
      CALL SHIFT3 (B,XS,YS,ZS)
830   CONTINUE
      GOTO 1000

1000  CONTINUE
      IF (FIRST) GOTO 1010
      CALL JOIN (B,C)

      GOTO 30

1010  CONTINUE
      CALL COPY (B,C)
      FIRST = .FALSE.
      GOTO 30

100   CONTINUE
      CALL CLDISC (FILNAM,10)

      CALL OPDISC('ASFDIN',10)
      FAC   =DIN('FAC   ')
      FORX  =DIN('FORX  ')
      FORY  =DIN('FORY  ')
```

```
      FRAX1 =DIN('FRAX1 ')
      FRAX2 =DIN('FRAX2 ')
      FRAY1 =DIN('FRAY1 ')
      FRAY2 =DIN('FRAY2 ')
      PICPLA=DIN('PICPLA')
      DISTNC=DIN('DISTNC')
      ROTATN=DIN('ROTATN')
      ELEVTN=DIN('ELEVTN')
      CALL CLDISC('WSFDIM',IO)
      CALL NEWPAG
      CALL START
C     CALL FACTOR(FAC)
      CALL FORMAT(FORX,FORY)
      CALL FRAME(FRAX1,FRAX2,FRAY1,FRAY2)
      CALL PLANE(PICPLA)
      CALL PEYE(0.0,0.0,0.0,DISTNC,ROTATN,ELEVTN)
      CALL DRAWIT(C)
      CALL NCLOSE
      CALL FINISH
C
C     IF THE SHAPE IS ACCORDING TO OUR REQUIREMENT SAY YES
C
      WRITE(6,2100)
2100  FORMAT(' Is the work Station of a required likeness YE/NO?')

      READ (5,2110)ANS
2110  FORMAT(A2/)
      IF (ANS.EQ.'NO'.OR.ANS.EQ.'N') GOTO 30
      IF (ANS.EQ.'YE'.OR.ANS.EQ.'Y') GOTO 2200

2200  CONTINUE
C
C     WORK STATION DETAILED DRAWN BY HELP OF THE ABOVE PROGRAM
C     IS FILED UNDER A UNIQUE TAG NUMBER
C      EACH WORK  STATION HAS GOT ITS OWN FILE
C
      WRITE(6,2300)
2300  FORMAT(' ENTER FILENAME/WSNAME=a tag No. of work station drawn')
      READ(5,2310)WSNAME
2310  FORMAT(A12)
      CALL OUT3D(C,WSNAME)
      STOP
      END
C
C
C     "FBOLT"  _  FOUNDATION BOLT
C     THIS IS A SUBROUTINE DRAWING AN ANCHORING BOLT
C
C...

      SUBROUTINE FBOLT (F)

      REAL D(39), E(88), F(127)
      CALL LINE3D(D,0.0,0.0,2.0,0.0,0.0,0.0,-2.0,10)
      CALL LINE3D(E,2.0,0.0,0.0,0.0,-2.0,0.0,0.0,10)
      CALL JOIN(D,E)
      CALL LINE3D(F,0.0,2.0,0.0,0.0,0.0,-8.0,0.0,10)
      CALL JOIN(E,F)
      RETURN
      END
```

7.

```
C
C        'OPERATOR' -3-D TEMPLATE
C
         SUBROUTINE OPERATOR (T)
C
C         TRUNK,ARMS,LEGS
C
         REAL A(100),B(500),C(900)
C         HEAD
         REAL F(1000),D(1200),T(2000)


         CALL BOX (A,55.0,60.0,35.0)
         CALL SHIFT3 (A,0.0,90.0,0.0)
         CALL BOX (B,10.0,90.0,20.0)
         CALL JOIN (A,B)
         CALL BOX (C,10.0,90.0,20.0)
         CALL SHIFT3 (C,35.0,0.0,0.0)
         CALL JOIN (B,C)
         CALL BOX (F,20.0,25.0,20.0)
         CALL SHIFT3 (F,27.0,150.0,0.0)
         CALL JOIN (C,F)
         CALL CONE (D,20.0,15.0,6)
         CALL TURN3D (D,270.0,0.0,0.0,1,T)
         CALL SHIFT3 (T,27.0,155.0,-20.0)
         CALL JOIN (F,T)
         CALL DRAWIT(T)

         RETURN
         END
C
C...
C
C... BUILDR UNDER THE NAME '*SFILE.FOR'
C
```

8.

```
5555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555
555555555555555555555555555555555  MIDDLESEX POLYTECHNIC VAXB 11/785   5555555555555555555555555555
5555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555

BBBBBBBB      OOOOOO    BBBBBBBB      11
BBBBBBBB      OOOOOO    BBBBBBBB      11
BB      BB  OO      OO  BB      BB  1111
BB      BB  OO      OO  BB      BB  1111
BB      BB  OO      OO  BB      BB    11
BB      BB  OO      OO  BB      BB    11
BBBBBBBB    OO      OO  BBBBBBBB      11
BBBBBBBB    OO      OO  BBBBBBBB      11
BB      BB  OO      OO  BB      BB    11
BB      BB  OO      OO  BB      BB    11
BB      BB  OO      OO  BB      BB    11
BB      BB  OO      OO  BB      BB    11
BBBBBBBB      OOOOOO    BBBBBBBB    111111
BBBBBBBB      OOOOOO    BBBBBBBB    111111

W   W   SSSS  RRRR   EEEEE   CCCC   AAA   L      L
W   W  S      R   R  E      C      A   A  L      L
W   W  S      R   R  E      C      A   A  L      L
W   W   SSS   RRRR   EEEE   C      A   A  L      L
W W W      S  R R    E      C      AAAAA  L      L
WW WW      S  R  R   E      C      A   A  L      L
W   W  SSSS   R   R  EEEEE   CCCC  A   A  LLLLL  LLLLL

    J   OOO   BBBB      1     1    666    000
    J  O   O  B   B    11    11   6      0   0
    J  O   O  B   B     1     1   6      0  00
    J  O   O  BBBB      1     1   6666   0 0 0
J   J  O   O  B   B     1     1   6   6  00  0
J   J  O   O  B   B     1     1   6   6  0   0
 JJJ    OOO   BBBB     111   111   666    000
```

```
160) queued to SYS$PRINT on 9-NOV-1987 12:13 by user BOB1, UIC [RESM0012,BOB1], under account RE
printer _LPA0: on 9-NOV-1987 12:14 from queue LPA0.

5555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555
555555555555555555555  Digital Equipment Corporation - VAX/VMS Version V4.5  5555555555555555
5555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555555
```

9.

```
C       PROGRAM "RECALLWS.FOR"
C       THIS PROGRAM IS RECALLING/PRESENTING THE WORK STATIONS DRAWN
C       BY HEPL OF PROGRAM WSFILE.FOR
C
        REAL V(5000)
        CHARACTER*12 WSNAME
        CHARACTER*12 TAGNO
        CALL OPDISC('WSFDIR',10)
        FAC    =DIN('FAC    ')
        FORX   =DIN('FORX   ')
        FORY   =DIN('FORY   ')
        FRAX1  =DIN('FRAX1  ')
        FRAX2  =DIN('FRAX2  ')
        FRAY1  =DIN('FRAY1  ')
        FRAY2  =DIN('FRAY2  ')
        PICPLA=DIN('PICPLA')
        DISTNC=DIN('DISTNC')
        ROTATN=DIN('ROTATN')
        ELEVTN=DIN('ELEVTN',10)
        CALL CLDISC('WSFDIR',10)
        CALL START
        CALL FACTOR(FAC)
        CALL FORMAT(FORX,FORY)
        CALL FRAME(FRAX1,FRAX2,FRAY1,FRAY2)
        CALL PLANE(PICPLA)
        CALL PEYE(0.0,0.0,0.0,DISTNC,ROTATN,ELEVTN)

        WRITE (6,50)
50      FORMAT (' Please write in the work Station tag No.')
        READ(5,60) TAGNO
60      FORMAT(A12)
        CALL IB30(V,TAGNO)
        CALL DRAWIT (V)
        CALL HCLOSE
        CALL FINISH
        STOP
        END

C
C... FILE UNDER THE NAME 'RECALLWS.FOR'
C
```

10.

```
66666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666
6666666666666666666666666666666  MIDDLESEX POLYTECHNIC VAXB 11/765   666666666666666666666666
66666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666

BBBBBBBB      OOOOOO     BBBBBBBB       11
BBBBBBBB      OOOOOO     BBBBBBBB       11
BB      BB  OO      OO   BB      BB   1111
BB      BB  OO      OO   BB      BB   1111
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BBBBBBBB    OO      OO   BBBBBBBB       11
BBBBBBBB    OO      OO   BBBBBBBB       11
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BBBBBBBB      OOOOOO     BBBBBBBB     111111
BBBBBBBB      OOOOOO     BBBBBBBB     111111

    CCCC    111    V     V   EEEEE    SSSS     333
   C         1     V     V   E       S        3   3
   C         1     V     V   E       S            3
   C         1     V     V   EEEE     SSS        3
   C         1     V     V   E           S        3
   C         1      V   V    E           S    3   3
    CCCC    111       V      EEEEE   SSSS      333


       J     OOO    BBBB           1        1      666       1
       J    O   O   B   B         11       11     6         11
       J    O   O   B   B          1        1     6          1
       J    O   O   BBBB           1        1     6666       1
   J   J    O   O   B   B          1        1     6   6      1
   J   J    O   O   B   B          1        1     6   6      1
    JJJ      OOO    BBBB          111      111     666      111
```

(1) queued to SYS$PRINT on 9-NOV-1987 12:14 by user BOB1, UIC [RESM0012,BOB1], under account RESM
printer _LPA0: on 9-NOV-1987 12:14 from queue LPA0.

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66666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666
6666666666666666666666666  Digital Equipment Corporation - VAX/VMS Version V4.5  66666666666666666
66666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666666
```

II.

```
C     "CIVES.FOR" PROGRAM IS WRITTEN FOR DESIGN OF CIVIL
C     ENGINEERING SPACE (SECTION OF A BAY) - CONSISTING
C     OF CIVIL ENGINEERING ELEMENTS (HERE PRESENTED AS
C     BOXES ONLY!)
C
C     DATA ARE READ IN MANUALLY ONLY
C     (EXEPT "DIN" FEEDING)
C
C     PRINTER AND VDU IS USED
C
C
      REAL  A(98),B(98), CESPAC (10000)
      REAL XWID(100),YWID(100),ZWID(100),XDIS(100),YDIS(100),ZDIS(100)
      REAL DGR(100),ZT(100),XT(100)

      INTEGER NCEE
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/


C     WRITE(6,10)ALPHA
C10    FORMAT('+',A2,$)
C     WRITE(6,10)SELECT
      WRITE(6,20)
20    FORMAT(' Program for design of a Civil Eng. Space(bay) in 3-D')
C     WRITE(6,10)DESEL
C     WRITE(6,10)GRAPHI
C
C     THE CIVIL ENGINEERING ELEMENTS AND
C     OTHER SPACES - ALL DIMESIONS SHOULD BE ENTERED IN DECIMETERS (DM)
      CALL START
      CALL OPDISC('CIVDIN',10)
      DISTNC=DIN('DISTNC')
      ROTATN=DIN('ROTATN')
      ELEVTN=DIN('ELEVTN')
      ZOOM  =DIN('ZOOM  ')
      NLX   =DIN('NLX   ')
      NLY   =DIN('NLY   ')
      NLZ   =DIN('NLZ   ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('CIVDIN',10)
      CALL FORMAT (80,0,60.0)
      CALL FRAME(-55.0,25.0,-35.0,25.0)
      CALL PEYE (0.0,0.0,0.0,DISTNC,ROTATN,ELEVTN)
      CALL PLANE (ZOOM)
      CALL MESH(NLX,NLY,NLZ,SPACE)

C     PRESENT SITUATION IS DRAWN

      CALL PRESENT
C
C     NEW DEVELOPMENT STARTS IF REQUESTED
C
      CALL DEVELOP
      CALL NCLOSE
      CALL FINISH
      STOP
```

```
      END
C...

      SUBROUTINE DEVELOP
      REAL  A(98),B(98), CESPAC (10000)
      REAL XWID(100),YWID(100),ZWID(100),XDIS(100),YDIS(100),ZDIS(100)
      REAL DGR(100),ZT(100),XT(100)

      INTEGER NCEE
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/


C     WRITE(6,10)ALPHA
C10    FORMAT('+',A2,$)
C     WRITE(6,10)SELECT
C
C    IF REQUESTED A NEW DEVELOPMENT FOLLOWS
C
50    CONTINUE
      WRITE (6,60)
60    FORMAT (' Do you wish to change/oevlop the Layout...YES/NO')
      READ (5,70)ANS
70    FORMAT (A2)
      IF (ANS.EQ.'NO'.OR.ANS.EQ.'N') GOTO 500
      IF (ANS.EQ.'YE'.OR.ANS.EQ.'N') GOTO 125
      WRITE (6,120)
120   FORMAT (' Please enter your response again')
      GOTO 50
125   CONTINUE
      CALL NEWPAG
130   CONTINUE
      CALL OPDISC ('CELDIM',10)
      READ(10,190,END=135)I,XWID(I),YWID(I),ZWID(I),XDIS(I),YDIS(I),
     &ZDIS(I),DGR(I),ZT(I),XT(I)

      WRITE(6,190)I,XWID(I),YWID(I),ZWID(I),XDIS(I),YDIS(I),
     &ZDIS(I),DGR(I),ZT(I),XT(I)
      GOTO 130
135   CONTINUE
      CALL CLDISC ('CELDIM',10)
C
C     WRITE(6,10)ALPHA
C     WRITE(6,10)SELECT
C     WRITE(6,140)
C140   FORMAT(' PLEASE ENTER NO. OF CIV.E. ELEMENTS(NCEE) REQUIRED')
C     WRITE(6,10)DESEL
C     WRITE(6,10)GRAPHI
C      READ(5,*)NCEE
C     WRITE(6,150)NCEE
C150   FORMAT(I3)
C     WRITE(6,10)ALPHA
C     WRITE(6,10)SELECT
C      WRITE(6,160)NCEE
C160   FORMAT(I3)
C     WRITE(6,10)DESEL
C     WRITE(6,10)GRAPHI
```

13.

```
C     WRITE(6,10)ALPHA
C     WRITE(6,10)SELECT
      WRITE(6,260)
260   FORMAT (' Please enter Item No., dim. & posn. of objects in dm
     &to end development/extending type 99 ')
      WRITE (6,270)
270   FORMAT (' I',2X,'XWID',4X,'YWID',4X,'ZWID',4X,'XDIS',4X,'YDIS',4X,
     &'ZDIS',5X,'DGR',5X,'ZT',5X,'XT')
C     WRITE(6,10)DESEL
C     WRITE(6,10)GRAPHI
280   CONTINUE
      READ(5,190)I,XWID(I),YWID(I),ZWID(I),XDIS(I),YDIS(I),ZDIS(I),
     &DGR(I),ZT(I),XT(I)
      IF (I.NE.99) GOTO 280
C     WRITE(6,10)ALPHA
C     WRITE(6,10)SELECT
      CALL OPDISC ('CELDIM',10)
      DO 200 I=1,99
      IF (XWID(I).EQ.0.0.AND.YWID(I).EQ.0.0) GOTO 200
      WRITE(6,190)I,XWID(I),YWID(I),ZWID(I),XDIS(I),YDIS(I),ZDIS(I),
     &DGR(I),ZT(I),XT(I)
190   FORMAT(I3,9F8.2)
C     WRITE(6,10)DESEL
C     WRITE(6,10)GRAPHI
      WRITE(10,190)I,XWID(I),YWID(I),ZWID(I),XDIS(I),YDIS(I),ZDIS(I),
     &DGR(I),ZT(I),XT(I)
200   CONTINUE
      CALL CLDISC ('CELDIM',10)
C
C     A PAUSE IS INTRODUCED FOR CHECKING
C     TO CONTINUE TYPE 'G'
C
      CALL NEWPAG
      DO 300 I = 1,99
      IF (XWID(I).EQ.0.0.AND.YWID(I).EQ.0.0) GOTO 300
      CALL BOX (A,XWID(I),YWID(I),ZWID(I))
      CALL SHIFT3(A,XDIS(I),YDIS(I),ZDIS(I))
      CALL TURN3D (A,DGR(I),ZT(I),XT(I),2,B)
      IF (I.EQ.1) CALL COPY (B,CESPAC)
      IF (I.NE.1) CALL JOIN (B,CESPAC)
300   CONTINUE
      CALL DRAWIT (CESPAC)
      CALL OUT3D (CESPAC,'CIVILD')
      GOTO 50
500   CONTINUE
      RETURN
      END

C
C...
      SUBROUTINE MESH(NLX,NLY,NLZ,SPACE)
      REAL A(1000)
      CALL GRIL3D(A,NLX,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLY,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLZ,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLY,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,.0,SPACE,.0)
      CALL DRAWIT(A)
```

```
      CALL GRIL3D(A,NLX,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLZ,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      RETURN
      END
C...
      SUBROUTINE PRESENT
      REAL  A(98),B(98), CESPAC (10000)
      REAL XWID(100),YWID(100),ZWID(100),XDIS(100),YDIS(100),ZDIS(100)
      REAL DGR(100),ZT(100),XT(100)

      INTEGER DCEE
      INTEGER SELECT,DESEL, ALPHA,GRAPH1
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPH1/"35/


C     WRITE(6,10)ALPHA
C10    FORMAT('+',A2,S)
C     WRITE(6,10)SELECT

      WRITE (6,20)
20    FORMAT(' LAYOUT...The present situation of development')
      CALL BELL
      CALL OPDISC('CIVDIM',10)
      DISINC=DIN('DISTNC')
      ROTATN=DIN('ROTATN')
      ELEVTN=DIN('ELEVTN')
      ZOOM  =DIN('ZOOM  ')
      NLX   =DIN('NLX   ')
      NLY   =DIN('NLY   ')
      NLZ   =DIN('NLZ   ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('CIVDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
      CALL OPDISC ('CELDIM',10)

60    CONTINUE
      READ(10,90,END=110)I,XWID(I),YWID(I),ZWID(I),XDIS(I),YDIS(I),
     &ZDIS(I),DGR(I),ZT(I),XT(I)
90     FORMAT(I3,9F8.2)
C      WRITE(6,90)I,XWID(I),YWID(I),ZWID(I),XDIS(I),YDIS(I),
C     &ZDIS(I),DGR(I),ZT(I),XT(I)
      GOTO 60
110   CONTINUE
      CALL CLDISC ('CELDIM',10)
      DO 150 I=1,99
      CALL BOX (A,XWID(I),YWID(I),ZWID(I))
      CALL SHIFT3(A,XDIS(I),YDIS(I),ZDIS(I))
      CALL TURN3D (A,DGR(I),ZT(I),XT(I),2,B)
      IF (I.EQ.1) CALL COPY (B,CESPAC)
      IF (I.NE.1) CALL JOIN (B,CESPAC)
150   CONTINUE
      CALL DRAWIT (CESPAC)
      RETURN
      END
```

15.

```
241     C....
241     C       THIS IS 'CIVES3.FOR PROGRAM
241     C       USING PRINTER (COMMANDS) AND 'DIR' FUNCTIONS
241     C
```

16.

```
1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
111111111111111111111111111111111111  MIDDLESEX POLYTECHNIC VAXB 11/785   1111111111111111111111111111111
1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111

          BBBBBBBB      OOOOOO     BBBBBBBB       11
          BBBBBBBB      OOOOOO     BBBBBBBB       11
          BB      BB  OO      OO  BB      BB    1111
          BB      BB  OO      OO  BB      BB    1111
          BB      BB  OO      OO  BB      BB      11
          BB      BB  OO      OO  BB      BB      11
          BBBBBBBB    OO      OO  BBBBBBBB        11
          BBBBBBBB    OO      OO  BBBBBBBB        11
          BB      BB  OO      OO  BB      BB      11
          BB      BB  OO      OO  BB      BB      11
          BB      BB  OO      OO  BB      BB      11
          BB      BB  OO      OO  BB      BB      11
          BBBBBBBB      OOOOOO    BBBBBBBB      111111
          BBBBBBBB      OOOOOO    BBBBBBBB      111111

        111   Y   Y  TTTTT  V   V   AAA   X   X   000    000
         1     Y Y     T    V   V  A   A   X X   0   0  0   0
         1     Y Y     T    V   V  A   A   X X   0  00  0  00
         1      Y      T    V   V  A   A    X    0 0 0  0 0 0
         1      Y      T    V   V  AAAAA   X X   00  0  00  0
         1      Y      T     V V   A   A  X   X  0   0  0   0
        111     Y      T      V    A   A  X   X   000    000

             J   000   BBBB          1     1    666   333
             J  0   0  B   B        11    11   6     3   3
             J  0   0  B   B         1     1   6         3
             J  0   0  BBBB          1     1   6666     3
         J   J  0   0  B   B         1     1   6   6     3
         J   J  0   0  B   B         1     1   6   6 3   3
          JJJ    000   BBBB         111   111   666   333
```

(1163) queued to SYS$PRINT on 9-NOV-1987 12:14 by user BOB1, UIC [RESM0012,BOB1], under account
on printer _LPA0: on 9-NOV-1987 12:16 from queue LPA0.

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111111111111111111111111  Digital Equipment Corporation - VAX/VMS Version V4.5  11111111111111111111111111
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```
      C        'IYTVAXU0.FOR'
      C        INTERACTIVE LAYOUT PROGRAM
      C        FOR MANUAL POSITIONING OF ANY 'OBJECTS'
      C        (WORK STATION,DEPARTMENTS,BAYS,HALLS IN PLOT ETC.)
      C        USING 'LARGEST VOLUMES' ONLY
      C
      C
               REAL X,Y,Z,P,XPOS,ZPOS,ANGLE
               INTEGER NWS
               COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
              &FNAME
               CHARACTER*12 FNAME(77)
               DATA X,Y,Z/231*999.0/
               DATA XPOS,ZPOS/154*999.0/
               DATA ANGLE/77*0.0/
               CALL START
               CALL WSVOL
               CALL OPDISC('MESDIM',10)
               FAC   =DIN('FAC   ')
               FORX  =DIN('FORX  ')
               FORY  =DIN('FORY  ')
               FRAX1 =DIN('FRAX1 ')
               FRAX2 =DIN('FRAX2 ')
               FRAY1 =DIN('FRAY1 ')
               FRAY2 =DIN('FRAY2 ')
               PICPLA=DIN('PICPLA')
               DISTNC=DIN('DISTNC')
               ROTATN=DIN('ROTATN')
               ELEVTN=DIN('ELEVTN')
               ZOOM  =DIN('ZOOM  ')
               NLX   =DIN('NLX   ')
               NLY   =DIN('NLY   ')
               NLZ   =DIN('NLZ   ')
               SPACE =DIN('SPACE ')
               CALL CLDISC('MESDIM',10)
      C        CALL FACTOR(FAC)
               CALL FORMAT(FORX,FORY)
               CALL FRAME(FRAX1,FRAX2,FRAY1,FRAY2)
               CALL PLANE(PICPLA)
               CALL PEYE(0.0,0.0,0.0,DISTNC,ROTATN,ELEVTN)
               CALL MESH(NLX,NLY,NLZ,SPACE)
               CALL NCLOSE
               CALL OPDISC('WSVOLD',10)
               NWS=1
      5        READ(10,10,END=20)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
      10       FORMAT(I5,3F6.2,A12)
               NWS=NWS+1
               GOTO 5
      20       CALL CLDISC('WSVOLD',10)
               NWS=NWS-1
               CALL PRESIT(NWS)
               CALL JOYST(NWS,PICPLA,DISTNC)
               CALL FINISH
               STOP
               END
      C...
               SUBROUTINE WSVOL
               INTEGER ANS,NWS
               COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
              &FNAME
```

```
          INTEGER SELECT,DESEL, ALPHA,GRAPHI
          CHARACTER*12 FNAME(77)
          DATA SELECT/"40033/
          DATA DESEL/"40433/
          DATA ALPHA/"30/
          DATA GRAPHI/"35/
C
C         OUTPUT OF CURRENT DATA FILE
C
          WRITE(6,10)ALPHA
   10     FORMAT('+',A2,$)
          WRITE(6,10)SELECT
          WRITE(6,20)
   20     FORMAT(' File of existing Work Station Module volumes')
          CALL OPDISC('WSVOLD',10)
   30     CONTINUE
          READ(10,40,END=60)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
   40     FORMAT(I5,3F8.2,A12)
          WRITE(6,50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
   50     FORMAT(I5,3F8.2,1X,A12)
C         PLEASE NOTE ABOVE WAS THE EXTRA SPACE '1X'DELETED
          GOTO 30
   60     CONTINUE
          CALL CLDISC('WSVOLD',10)
C
C         EXTEND FILE?
C
          WRITE(6,70)
   70     FORMAT(' Do you wish to extend/update the existing file-YE or NO')
          WRITE(6,10)DESEL
          WRITE(6,10)GRAPHI
   80     READ(5,85)ANS
   85     FORMAT(A2)
          IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 150
          IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 100
          WRITE(6,90)
   90     FORMAT(' Please enter your response again')
          GOTO 80
  100     CONTINUE
          WRITE(6,110)
  110     FORMAT(' PLEASE ENTER WS No.,X,Y,Z,DIM OF WS AND TAG No OF WS...
         &TO END EXTENDING TYPE 77')
  120     CONTINUE
          READ(5,40)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
          IF(J.NE.77)GOTO 100
C
C         OUTPUT LATEST DATA TO DISC AND TERMINAL
C
          WRITE(6,10)ALPHA
          WRITE(6,10)SELECT
          WRITE(6,20)
          CALL OPDISC('WSVOLD',10)
  130     CONTINUE
          DO 140 J=1,76
          IF (X(J).EQ.999.0.AND.Y(J).EQ.999.0)GOTO 140
          WRITE(10,40)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
          WRITE(6,50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
  140     CONTINUE
          CALL CLDISC('WSVOLD',10)
          WRITE(6,10)DESEL
```

```
      WRITE(6,10)GRAPHI
150   CONTINUE
      RETURN
      END
C...
C...
      SUBROUTINE MESH(NLX,NLY,NLZ,SPACE)
      REAL A(1000)
      CALL GRIL3D(A,NLX,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLY,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLZ,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLY,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLX,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLZ,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      RETURN
      END
C...
C     THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION

      SUBROUTINE PRESIT(NWS)
      REAL P(500),F(2000),G(2000),T(2000),U(2000)
      INTEGER NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME(77)
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/
C     PRINTING THE PRESENT SITUATION OF LAYOUT DEVELOPMENT
      WRITE(6,10)
10    FORMAT(' LAYOUT-the existing situation of development')
      CALL BELL
      CALL OPDISC('MESDIM',10)
      NLX   =DIN('NLX    ')
      NLY   =DIN('NLY    ')
      NLZ   =DIN('NLZ    ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('MESDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
      CALL OPDISC('WSPOSD',11)
      DO 60 K=1,76
50    READ(11,60,END=70)J,XPOS(J),ZPOS(J),ANGLE(J),FNAME(J)(1:12)
60    FORMAT(I5,3F10.2,A12)
      CALL BOX(P,X(J),Y(J),Z(J))
      XWORK = XPOS(J)
      ZWORK = ZPOS(J)
      CALL TURN3D(P,ANGLE(J),0.0,0.0,2,R)
      CALL HERSH(FNAME(J)(1:12),6,2,60.0,Q)
      CALL TRANSP(Q,T)
      CALL TURN3D(T,270.0,0.0,0.0,0.0,1,U)
      CALL JOIN(R,U)
      CALL DRAW3D(U,1.0,XWORK,0.0,ZWORK,1)
```

```
60    CONTINUE
70    CALL CLDISC('*SPOSD',11)
      RETURN
      END
C
C     'JOTST' SUBROUTINE IS FOR MANIPULATION OF ANY
C     'OBJECT' USING ORDER 'N' (NOT VIA TAG NOS.!)
C

C...
      SUBROUTINE JOTST(NWS,PICPLA,DISTNC)
      REAL P(500),R(2000),Q(2000),T(2000),U(2000)
      INTEGER NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FRAME
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FRAME(77)
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/

C     CHANGE OF LAYOUT IS CONSIDERED
      WRITE(6,85)ALPHA
85    FORMAT('+',A2,$)
      WRITE(6,85)SELECT
      WRITE(6,90)
90    FORMAT(' Do you wish to develope the layout-YE or NO')
      WRITE(6,85)DESEL
      WRITE(6,85)GRAPHI
100   READ(5,110)ANS
110   FORMAT(A2)
      IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 250
      IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 150
120   FORMAT(' Please enter your response again')
150   CONTINUE
160   CALL BELL
      CALL PLIT(3.0,-5.0,3)
      WRITE(6,170)
170   FORMAT(' Which workstation?')
      READ(5,*)N
      IF(N.EQ.0)GOTO 190
      CALL BOX(P,X(N),Y(N),Z(N))
      CALL SCREEN(ICHAR,X1,Y1)
      CALL SCREEN(ICHAR,X2,Y2)
      CALL NEWPAG
      CALL BELL
      CALL OPDISC('MESDIM',10)
      NLX   =DIN('NLX    ')
      NLY   =DIN('NLY    ')
      NLZ   =DIN('NLZ    ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('MESDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
      ANGLE(N) = ATAN2(Y2-Y1,X2-X1)*180.0/3.14159265
      XPOS(N) = Y1*DISTNC/PICPLA
      ZPOS(N) = X1*DISTNC/PICPLA
      DO 180 K = 1,76
      CALL BOX(P,X(K),Y(K),Z(K))
      XWORK = XPOS(K)
```

```
      ZWORK = ZPOS(K)
      IF(XWORK.EQ.999.0.AND.ZWORK.EQ.999.0)GOTO 180
      CALL TURN3D(P,ANGLE(K),0.0,0.0,2,R)
      CALL HERSH(FNAME(K)(1:12),6,2,60.0,0)
      CALL TRANSP(Q,T)
      CALL TURN3D(T,270.0,0.0,0.0,1,U)
      CALL JOIN(R,U)
      CALL DRAW3D(U,1.0,XWORK,0.0,ZWORK,1)
180   CONTINUE
      GOTO 160
190   CONTINUE
      CALL OPDISC('WSPOSD',11)
      DO 200 K = 1,76
      IF(XPOS(K).EQ.999.0.AND.ZPOS(K).EQ.999.0)GOTO 200
      WRITE(10,210)K,XPOS(K),ZPOS(K),ANGLE(K),FNAME(K)(1:12)
210   FORMAT(I5,3F10.2,A12)
200   CONTINUE
      CALL CLDISC('WSPOSD',11)
250   RETURN
      END
C...
C....
C     FILE UNDER 'ITTVAX00.FOR'
C
```

22.

```
2222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222
22222222222222222222222222222222  MIDDLESEX POLYTECHNIC VAXB 11/785   222222222222222222222222222
2222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222

                    BBBBBBBB      OOOOOO     BBBBBBBB        11
                    BBBBBBBB      OOOOOO     BBBBBBBB        11
                    BB       BB  OO        OO  BB       BB    1111
                    BB       BB  OO        OO  BB       BB    1111
                    BB       BB  OO        OO  BB       BB      11
                    BB       BB  OO        OO  BB       BB      11
                    BBBBBBBB     OO        OO  BBBBBBBB         11
                    BBBBBBBB     OO        OO  BBBBBBBB         11
                    BB       BB  OO        OO  BB       BB      11
                    BB       BB  OO        OO  BB       BB      11
                    BB       BB  OO        OO  BB       BB      11
                    BB       BB  OO        OO  BB       BB      11
                    BBBBBBBB      OOOOOO     BBBBBBBB       111111
                    BBBBBBBB      OOOOOO     BBBBBBBB       111111

             III   Y   Y  TTTTT  W   W   SSSS  FFFFF   III   L       EEEEE
              I    Y   Y    T    W   W  S      F        I    L       E
              I     Y Y     T    W   W  S      F        I    L       E
              I      Y      T    W   W   SSS   FFFF     I    L       EEEE
              I      Y      T    W W W      S  F        I    L       E
              I      Y      T    WW WW      S  F        I    L       E
             III     Y      T    W   W  SSSS   F       III   LLLLL   EEEEE

                    J   OOO   BBBB          1      1     666    4   4
                    J  O   O  B   B        11     11    6       4   4
                    J  O   O  B   B         1      1    6       4   4
                    J  O   O  BBBB          1      1    6666    44444
                J   J  O   O  B   B         1      1    6   6       4
                J   J  O   O  B   B         1      1    6   6       4
                 JJJ    OOO   BBBB         111    111    666        4

.1164) queued to SYS$PRINT on 9-NOV-1987 12:14 by user BOB1, UIC [RESM0012,BOB1], under account
) printer _LPA0: on 9-NOV-1987 12:19 from queue LPA0.

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222222222222222222222222  Digital Equipment Corporation - VAX/VMS Version V4.5  22222222222222222
2222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222.
```

```
C       PROGRAM INTERACTIVE LAYOUT (IYTWSFILE)
C       INCORPORATING WORK STATION DETAILS (WSFILE)
C       READING FROM FILES 'WSNAME'
C       DETAILED WORK STATIONS ARE RECALLED VIA
C       ORDER NOS 'N' ONLY ! (NOT VIA TAG NOS. !)
C
C
        REAL X,Y,Z,P,XPOS,ZPOS,ANGLE
        INTEGER NWS
        COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
       &FNAME
        CHARACTER*12 WSNAME
        CHARACTER*12 FNAME(77)
        DATA X,Y,Z/231*999.0/
        DATA XPOS,ZPOS/154*999.0/
        DATA ANGLE/77*0.0/
        CALL START
        CALL WSVOL
        CALL OPDISC('MESDIM',10)
        FAC   =DIN('FAC   ')
        FORX  =DIN('FORX  ')
        FORY  =DIN('FORY  ')
        FRAX1 =DIN('FRAX1 ')
        FRAX2 =DIN('FRAX2 ')
        FRAY1 =DIN('FRAY1 ')
        FRAY2 =DIN('FRAY2 ')
        PICPLA=DIN('PICPLA')
        DISTNC=DIN('DISTNC')
        ROTATN=DIN('ROTATN')
        ELEVTN=DIN('ELEVTN')
        ZOOM  =DIN('ZOOM  ')
        NLX   =DIN('NLX   ')
        NLY   =DIN('NLY   ')
        NLZ   =DIN('NLZ   ')
        SPACE =DIN('SPACE ')
        CALL CLDISC('MESDIM',10)
        CALL FACTOR(FAC)
        CALL FORMAT(FORX,FORY)
        CALL FRAME(FRAX1,FRAX2,FRAY1,FRAY2)
        CALL PLANE(PICPLA)
        CALL PEYE(0.0,0.0,0.0,DISTNC,ROTATN,ELEVTN)
        CALL MESH(NLX,NLY,NLZ,SPACE)
        CALL NCLOSE
        CALL OPDISC('WSVOLD',10)
        NWS=1
5       READ(10,10,END=20)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
10      FORMAT(I5,3F8.2,A12)
        NWS=NWS+1
        GOTO 5
20      CALL CLDISC('WSVOLD',10)
        NWS=NWS-1
        CALL PRESIT(NWS)
        CALL JOYST(NWS,PICPLA,DISTNC)
        CALL FINISH
        STOP
        END
C...
        SUBROUTINE WSVOL
        INTEGER ANS,NWS
        COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
```

```
      &FNAME
       INTEGER SELECT,DESEL, ALPHA,GRAPH1
       CHARACTER*12 FNAME(77)
       DATA SELECT/"40033/
       DATA DESEL/"40433/
       DATA ALPHA/"30/
       DATA GRAPH1/"35/
C
C      OUTPUT OF CURRENT DATA FILE
C
       WRITE(6,10)ALPHA
 10    FORMAT('+',A2,$)
       WRITE(6,10)SELECT
       WRITE(6,20)
 20    FORMAT(/// ' File of existing work Station Module volumes'//)
       WRITE (6,35)' Item','Dim X','Dim Y','Dim Y','Tag No'
 35    FORMAT (A5,3A8,A7/)
       CALL OPDISC('WSVOLD',10)
 30    CONTINUE
       READ(10,40,END=60)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
 40    FORMAT(I5,3F8.2,A12)
       WRITE(6,50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
 50    FORMAT(I5,3F8.2,1X,A12)
C      PLEASE NOTE ABOVE WAS THE EXTRA SPACE '1X'DELETED
       GOTO 30
 60    CONTINUE
       CALL CLDISC('WSVOLD',10)
C
C      EXTEND FILE?
C
       WRITE(6,70)
 70    FORMAT( / ' Do you wish to extend/update the  file-YE or NO'/)
       WRITE(6,10)DESEL
       WRITE(6,10)GRAPH1
 80    READ(5,85)ANS
 85    FORMAT(A2)
       IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 150
       IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 100
C
C      ERROR MESSAGE
C
       WRITE(6,90)
 90    FORMAT(' Please enter your response again ! use CAPITALS !')
       GOTO 80
 100   CONTINUE
C
C      NEW ENTRY IS WRITTEN
C
       WRITE(6,110)
 110   FORMAT(' Please enter Item No. Dim of W.S. X,Y,Z, and TAG No
      &...TO END EXTENDING TYPE 77')
 120   CONTINUE
       READ(5,40)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
       IF(J.NE.77)GOTO 100
C
C      OUTPUT LATEST DATA TO DISC AND TERMINAL
C
       WRITE(6,10)ALPHA
       WRITE(6,10)SELECT
       WRITE(6,20)
```

```
      CALL OPDISC('WSVOLD',10)
130   CONTINUE
      DO 140 J=1,76
      IF (X(J).EQ.999.0.AND.Y(J).EQ.999.0)GOTO 140
      WRITE(10,40)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
      WRITE(6,50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
140   CONTINUE
      CALL CLDISC('WSVOLD',10)
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPH1
150   CONTINUE
      RETURN
      END
C...
C...
      SUBROUTINE MESH(NLX,NLY,NLZ,SPACE)
      REAL A(1000)
      CALL GRID3D(A,NLX,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLY,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLZ,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLY,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLX,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLZ,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      RETURN
      END
C...
C     THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION

      SUBROUTINE PRESIT(NWS)
      REAL P(500),R(2000),Q(2000),T(2000),U(2000),V(7000)
      INTEGER NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME
      INTEGER SELECT,DESEL, ALPHA,GRAPH1
      CHARACTER*12 FNAME(77)
      CHARACTER*12 WSNAME
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPH1/"35/
C
C     PRINTING THE PRESENT SITUATION OF LAYOUT DEVELOPMENT
C
      WRITE (6,5)ALPHA
5     FORMAT('+',A2,$)
      WRITE (6,5)SELECT
      WRITE(6,10)
10    FORMAT(' LAYOUT-the existing situation of development'////)
      WRITE (6,5)DESEL
      WRITE (6,5)GRAPH1
      CALL BELL
      CALL OPDISC('MESDIM',10)
      NLX   =DIM('NLX   ')
      NLY   =DIM('NLY   ')
```

```
      NLZ   =DIN('NLZ   ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('MESDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
      CALL OPDISC('WSPOSD',11)
      DO 80 K=1,76
      READ(11,60,END=70)J,XPOS(J),ZPOS(J),ANGLE(J),FNAME(J)(1:12)
60    FORMAT(I5,3F10.2,A12)
      CALL BOX(P,X(J),Y(J),Z(J))
      XWORK = XPOS(J)
      ZWORK = ZPOS(J)
      IF(XWORK.EQ.999.0.AND.ZWORK.EQ.999.0)GOTO 80
      CALL TURN3D(P,ANGLE(J),0.0,0.0,2,R)
      WSNAME=FNAME(J)
      CALL HERSH(FNAME(J)(1:12),6,2,60.0,Q)
      CALL TRANSP(Q,T)
      CALL TURN3D(T,270.0,0.0,0.0,1,U)
      CALL JOIN(R,U)
C
C     DETAIL SHAPE OF THE WORK STATION IS RETRIEVED
C     FROM A DISK
C
      CALL IN3D(V,WSNAME)
      CALL JOIN(U,V)
      CALL DRAW3D(V,1.0,XWORK,0.0,ZWORK,1)
80    CONTINUE
70    CALL CLDISC('WSPOSD',11)
      RETURN
      END
C...

C...
      SUBROUTINE JOYST(NWS,PICPLA,DISTRC)
      REAL P(500),R(2000),Q(2000),T(2000),U(2000),V(7000)
      INTEGER ANS, NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME(77)
      CHARACTER*12 WSNAME
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/

C     CHANGE OF LAYOUT IS CONSIDERED
      WRITE(6,85)ALPHA
85    FORMAT('+',A2,$)
      WRITE(6,85)SELECT
      WRITE(6,90)
90    FORMAT(' Do you wish to develope the layout-YE or NO')
      WRITE(6,85)DESEL
      WRITE(6,85)GRAPHI
100   READ(5,110)ANS
110   FORMAT(A2)
      IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 250
      IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 150
120   FORMAT(' Please enter your response again')
150   CONTINUE
160   CALL BELL
```

```
              CALL PLIT(3.0,-5.0,3)
              WRITE(6,170)
      170     FORMAT(' Which workstation?')
              READ(5,*)N
              IF(N.EQ.0)GOTO 190
              CALL BOX(P,X(N),Y(N),Z(N))
              CALL SCREEN(ICHAR,X1,Y1)
              CALL SCREEN(ICHAR,X2,Y2)
              CALL NEWPAG
              CALL BELL
              CALL OPDISC('MESDIM',10)
              NLX   =DIN('NLX   ')
              NLY   =DIN('NLY   ')
              NLZ   =DIN('NLZ   ')
              SPACE =DIN('SPACE ')
              CALL CLDISC('MESDIM',10)
              CALL MESH(NLX,NLY,NLZ,SPACE)
              ANGLE(N) = ATAN2(Y2-Y1,X2-X1)*180.0/3.14159265
              XPOS(N) = Y1*DISTNC/PICPLA
              ZPOS(N) = X1*DISTNC/PICPLA
              DO 180 K = 1,76
              CALL BOX(P,X(K),Y(K),Z(K))
              XWORK = XPOS(K)
              ZWORK = ZPOS(K)
              IF(XWORK.EQ.999.0.AND.ZWORK.EQ.999.0)GOTO 180
              CALL TURN3D(P,ANGLE(K),0.0,0.0,2,R)
              WSNAME=FNAME(K)
              CALL HERSH(FNAME(K)(1:12),6,2,60.0,Q)
              CALL TRANSP(Q,T)
              CALL TURN3D(T,270.0,0.0,0.0,1,U)
              CALL JOIN(R,U)
      C
      C       DETAIL SHAPE OF THE WORK STATION IS RETRIEVED
      C       FROM A DISK
      C
              CALL IN3D(V,WSNAME)
              CALL JOIN(U,V)
              CALL DRAW3D(V,1.0,XWORK,0.0,ZWORK,1)
      180     CONTINUE
              GOTO 160
      190     CONTINUE
              CALL OPDISC('WSPOSD',10)
              DO 200 K = 1,76
              IF(XPOS(K).EQ.999.0.AND.ZPOS(K).EQ.999.0)GOTO 200
              WRITE(10,210)K,XPOS(K),ZPOS(K),ANGLE(K),FNAME(K)(1:12)
      210     FORMAT(I5,3F10.2,A12)
      200     CONTINUE
              CALL CLDISC('WSPOSD',10)
      250     RETURN
              END
      C...
      C....
      C       FILE UNDER 'IYTWSFILE'
```

28.

```
3333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333
333333333333333333333333333333  MIDDLESEX POLYTECHNIC VAXB 11/785   33333333333333333333333333
3333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333
```

```
BBBBBBBB      000000     BBBBBBBB        11
BBBBBBBB      000000     BBBBBBBB        11
BB      BB  00      00   BB      BB    1111
BB      BB  00      00   BB      BB    1111
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BBBBBBBB    00      00   BBBBBBBB        11
BBBBBBBB    00      00   BBBBBBBB        11
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BBBBBBBB      000000     BBBBBBBB      111111
BBBBBBBB      000000     BBBBBBBB      111111
```

```
PPPP    000    SSSS   CCCC  L       AAA    SSSS  H   H  55555
P   P  0   0  S      C      L      A   A  S      H   H  5
P   P  0   0  S      C      L      A   A  S      H   H  555
PPPP   0   0   SSS   C      L      A   A   SSS   HHHHH     5
P      0   0      S  C      L      AAAAA      S  H   H     5
P      0   0      S  C      L      A   A      S  H   H  5  5
P       000   SSSS    CCCC  LLLLL  A   A  SSSS   H   H   555
```

```
    J   000   BBBB         1    1    666  55555
    J  0   0  B   B       11   11   6     5
    J  0   0  B   B        1    1   6     555
    J  0   0  BBBB         1    1   6666     5
J   J  0   0  B   B        1    1   6   6    5
J   J  0   0  B   B        1    1   6   6 5  5
 JJJ    000   BBBB        111  111   666   555
```

(1165) queued to SYS$PRINT on 9-NOV-1987 12:15 by user BOB1, BIC [RESM0012,BOB1], under account
n printer _LPA0: on 9-NOV-1987 12:20 from queue LPA0.

```
3333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333
3333333333333333333333  Digital Equipment Corporation - VAX/VMS Version V4.5  333333333333333
3333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333333
```

```
C       "POSCLASH5.FOR" PROGRAM IS AN INTRACTIVE PROGRAM
C       FOR AUTOMATIC POSITIONING OF A LINE OR A GROUP OF
C       WORK STATION WITHIN BUILDING (CIVIL ENG.SPACE)
C       INCLUDING COLLISION COURSE FINDING WITH
C       OBJECTS (WALLS,COLUMNS ETC) WITHIN BUILDING
C       AND FACILITY TO ENTER READY BUILT LAYOUT AT ANY WORK STATION
C       FOR RE-LAYOUT VIA JOYSTICK AND AUTOMATIC
C
C
C
C
C       THE "MFEED" PROGRAM RESULTS (OR DR.C. SYSTEM) ARE INTRODUCED
C       AND W.S. IN AN PRODUCTION LINE ORDER VIA "WSVTDIC"
C       DISC WSVTDR.DAT ARE ENTERED
C
C
C
C       GENERALLY: I AM SOLVING A TASK OF AUTOMATIC POSITIONING
C       OF GROUP OF WORK STATION (MAX. NUMBER OF W.S. IS 77!).
C
C
C...
C       PROGRAM INTERACTIVE LAYOUT (INTLAY)
        INTEGER NWS
        COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
       &FNAME(77)
        CHARACTER*12 FNAME
        CHARACTER*12 WSNAME

        INTEGER SELECT,DESEL, ALPHA,GRAPHI
        DATA X,Y,Z/231*999.0/
        DATA XPOS,ZPOS/154*999.0/
        DATA ANGLE/77*0.0/
        DATA SELECT/"40033/
        DATA DESEL/"40433/
        DATA ALPHA/"30/
        DATA GRAPHI/"35/
        CALL START
        CALL WSVOL
        CALL OPDISC('MESDIM',10)
        FAC   =DIM('FAC    ')
        FORX  =DIM('FORX   ')
        FORY  =DIM('FORY   ')
        FRAX1 =DIM('FRAX1  ')
        FRAX2 =DIM('FRAX2  ')
        FRAY1 =DIM('FRAY1  ')
        FRAY2 =DIM('FRAY2  ')
        PICPLA=DIM('PICPLA')
        DISTNC=DIM('DISTNC')
        ROTATN=DIM('ROTATN')
        ELEVTN=DIM('ELEVTN')
        ZOOM  =DIM('ZOOM   ')
        NLX   =DIM('NLX    ')
        NLY   =DIM('NLY    ')
        NLZ   =DIM('NLZ    ')
        SPACE =DIM('SPACE  ')
        CALL CLDISC('MESDIM',10)
C       CALL FACTOR(FAC)
        CALL FORMAT(FORX,FORY)
        CALL FRAME(FRAX1,FRAX2,FRAY1,FRAY2)
```

```
      CALL PLANE(PICPLA)
      CALL PEYE(0.0,0.0,0.0,DISTNC,ROTATN,ELEVTN)
      CALL MESH(NLX,NLY,NLZ,SPACE)
      CALL OPDISC('WSVOLD',10)
      NWS=1
5     READ(10,10,END=20)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
10    FORMAT(I5,3F6.2,A12)
      NWS=NWS+1
      GOTO 5
20    CALL CLDISC('WSVOLD',10)
      NWS=NWS-1
      CALL PRESIT (NWS)
40    CONTINUE
      WRITE(6,50)ALPHA
50    FORMAT('+',A2,$)
      WRITE(6,50)SELECT
      WRITE(6,70)
70    FORMAT (' Do you want to continue/change the layout...
     &YE or NO ? ')
      WRITE(6,50)DESEL
      WRITE(6,50)GRAPH1
      READ(5,85)ANS
85    FORMAT(A2)
      IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 2900
      IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 100
      WRITE(6,50)ALPHA
      WRITE(6,50)SELECT
      WRITE(6,90)
90    FORMAT(' Please enter your response again - use CAPITALS')
      WRITE(6,50)DESEL
      WRITE(6,50)GRAPH1
      GOTO 40
100   CONTINUE
C
      CALL POSIT(PICPLA,DISTNC)
2900  CONTINUE
      CALL NCLOSE
      CALL FINISH
      STOP
      END
C
C     THIS IS THE END OF MAIN POSCOL2.FOR PROGRAM
C

C...
      SUBROUTINE WSVOL
      INTEGER ANS,NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME(77)
      INTEGER SELECT,DESEL, ALPHA,GRAPH1
      CHARACTER*12 FNAME
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPH1/"35/
C
C     OUTPUT OF CURRENT DATA FILE
C
      WRITE(6,10)ALPHA
10    FORMAT('+',A2,$)
```

```
              WRITE(6,10)SELECT
              WRITE(6,20)
       20     FORMAT(' File of existing Work Station Module volumes')
              CALL UPDISC('WSVOLD',10)
       30     CONTINUE
              READ(10,40,END=60)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
       40     FORMAT(I5,3F8.2,A12)
       C      WRITE(6,10)ALPHA
       C      WRITE(6,10)SELECT
              WRITE(6,50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
       50     FORMAT(I5,3F8.2,1X,A12)
       C      WRITE(6,10)DESEL
       C      WRITE(6,10)GRAPHI
       C      PLEASE NOTE ABOVE WAS THE EXTRA SPACE '1X'DELETED
              GOTO 30
       60     CONTINUE
              CALL CLDISC('WSVOLD',10)
       C
       C      EXTEND FILE?
       C
       C      CALL BELL
       C      WRITE(6,10)ALPHA
       C      WRITE(6,10)SELECT
              WRITE(6,70)
       70     FORMAT(' Do you wish to extend/update the existing file...
             &YE or NO')
              WRITE(6,10)DESEL
              WRITE(6,10)GRAPHI
       80     READ(5,85)ANS
       85     FORMAT(A2)
              IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 150
              IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 100
       C      WRITE(6,10)ALPHA
       C      WRITE(6,10)SELECT
              WRITE(6,90)
       90     FORMAT(' Please enter your response again')
       C      WRITE(6,10)DESEL
       C      WRITE(6,10)GRAPHI
              GOTO 80
       100    CONTINUE
              WRITE(6,110)
       110    FORMAT(' PLEASE ENTER WS No.,X,Y,Z,DIM OF WS AND TAG No OF WS...
             &TO END EXTENDING TYPE 77')
       120    CONTINUE
              READ(5,40)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
              IF(J.NE.77)GOTO 100
       C
       C      OUTPUT LATEST DATA TO DISC AND TERMINAL
       C
              WRITE(6,10)ALPHA
              WRITE(6,10)SELECT
              WRITE(6,20)
              CALL UPDISC('WSVOLD',10)
       130    CONTINUE
              DO 140 J=1,76
              IF (X(J).EQ.999.0.AND.Y(J).EQ.999.0)GOTO 140
              WRITE(10,40)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
              WRITE(6,50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
       140    CONTINUE
              CALL CLDISC('WSVOLD',10)
```

```
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
  150 CONTINUE
      RETURN
      END
C...
      SUBROUTINE MESH(NLX,NLY,NLZ,SPACE)
      REAL A(1000)
      CALL GRID3D(A,NLX,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLY,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLZ,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLY,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLX,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRID3D(A,NLZ,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      RETURN
      END

C...
      SUBROUTINE PRESIT (NWS)
C
C     THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION
C
      REAL P(500),R(2000),W(2000),T(2000),U(2000)
      REAL CESPAC(10000)
      INTEGER NWS
      COMMON/BCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME(77)
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/
C     PRINTING THE PRESENT SITUATION OF LAYOUT DEVELOPMENT
      WRITE(6,10)ALPHA
   10 FORMAT('+',A2,$)
      WRITE(6,10)SELECT
      WRITE(6,20)
   20 FORMAT(' LAYOUT...The existing situation of development')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
      CALL BELL
      CALL OPDISC('MESDIM',10)
      NLX   =DIN('NLX   ')
      NLY   =DIN('NLY   ')
      NLZ   =DIN('NLZ   ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('MESDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
C
C     BUILDING IS CALLED IN
C
      CALL IN3D (CESPAC,'CIVILD')
      CALL DRAWIT (CESPAC)
```

```
      CALL OPDISC('WSVTOR',12)
40    READ(12,60,END=50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
      CALL OPDISC('WSPOSA',11)
50    READ(11,60,END=90)J,XPOS(J),ZPOS(J),ANGLE(J),FNAME(J)(1:12)
60    FORMAT(I5,3F8.2,A12)
      CALL BOX(P,X(J),Y(J),Z(J))
      XWORK = XPOS(J)
      ZWORK = ZPOS(J)
      CALL HERSH(FNAME(J)(1:12),6,2,60.0,G)
      CALL TRANSP(G,T)
      CALL TURN3D(T,270.0,0.0,0.0,1,U)
      CALL JOIN(P,U)
      CALL TURN3D(U,ANGLE(J),0.0,0.0,2,R)
      CALL SHIFT3 (R,XWORK,0.0,ZWORK)
      CALL DRAWIT (R)
C     CALL DRAW3D(U,1.0,XWORK,0.0,ZWORK,1)
      GOTO 40
90    CONTINUE
      CALL CLDISC('WSPOSA',11)
      CALL CLDISC('WSVTOR',12)


      RETURN
      END
C...
C...
      SUBROUTINE POSIT(PICPLA,DISTWC)
C
C     THIS IS A SUBROUTINE FOR ENTIRE POSITIONING OF W.S.
C     INCLUDING SUBROUTINE JOY2 (FOR MANUAL POSITION OF ONE W.S.)
C     SUBROUTINE JOUST (FOR ENTRY AT ANY SITUATION AND FOR
C     GROUP TECHNOLOGY LAYOUT
C     AND SUBROUTINE PLACE (FOR AUTOMATIC PLACING OF SELECTED
C     GROUP/LINE OF WORK STATIONS INTO AN OPTIMAL PLACE)
C

      REAL X,Y,Z,XPOS,ZPOS,ANGLE,XSUM,ZSUM
      REAL XS,ZS,AS
      REAL JR
      REAL P(500),R(2000),Q(2000),T(7300),U(2000),G(2000),V(2000)
      REAL W(7000),CESPAC(10000)
      LOGICAL FOUND
      INTEGER NWS,ANS,SUMJ,RESULT
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME(77)
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME
      CHARACTER*12 WSNAME
      DATA X,Y,Z/231*999.0/
      DATA XPOS,ZPOS/154*999.0/
      DATA ANGLE/77*0.0/
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/
C
C
15    CONTINUE
      WRITE(6,10)ALPHA
10    FORMAT('+',A2,$)
```

```
      WRITE(6,10)SELECT

      WRITE (6,20)
20    FORMAT (' You are now in POSITIONING MODE ')
      WRITE (6,22)
22    FORMAT (' Are you starting a NEW layout,from the first W.St.
     &in technological order?'/'...YES or NO')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI

42    CONTINUE

      READ (5,43 )ANS
43    FORMAT (A2)
      IF (ANS.EQ.'NO'.OR.ANS.EQ.'N') GOTO 7000
      IF (ANS.EQ.'YE'.OR.ANS.EQ.'Y') GOTO 25
      WRITE (6,44)
44    FORMAT (' Please enter your response again - use capitals')
      GOTO 42
7000  CONTINUE
      CALL JOYST (NAS,PICPLA,DISINC,L)
      GOTO 7100


25    CONTINUE
C
C     WORK STATION (VOLUMES) IN A REORGANISED TECHNOLOGICAL
C     ORDER ARE INTRODUCED VIA DISC 'WSVTOR'.
C     DISC 'WSVTOR' IS FED VIA PROGRAM WSVTOTU,FOR WHICH
C     IS NOT AN INTEGRAL PART OF THIS PROGRAM 'POSCOL'
C     (COMPUTER TIME SAVING !  DURING RUN OF 'POSCOL')
C
      CALL OPDISC ('WSVTOR',12)
C
C     READING IN THE 'first' WORK STATION ONLY
C
      READ (12,30)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
30    FORMAT (I5,3F8.2,A12)
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT
      WRITE (6,50)
50    FORMAT (' Do you wish to POSITIon the considered work
     &Station manually ... YE or NO'/)
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
100   READ(5,110)ANS
110   FORMAT(A2)
      IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 405
      IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 150
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT
      WRITE (6,120)
120   FORMAT(' Please enter your response again')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
      GOTO 100
C
C     IF YOU SELECT 'NO' YOU ARE GOING DIRECTLY INTO
C     THE AUTOMATIC POSITIONING PROGRAM -SUBROUTINE "PLACE"
C
```

```
150   CONTINUE
160   CALL BELL
      WRITE (6,200)
200   FORMAT (' Use joystic for corrective action')
C
C     BUILDING IS CALLED IN
C
      CALL IN3D (CESPAC,'CIVILD')
      CALL DRAWIT (CESPAC)
      CALL JOY2 (J,PICPLA,DISTNC,G,XS,ZS,AS)


405   CONTINUE
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT
      WRITE (6,410)
410   FORMAT (' Do you wish to continue developing the layout...
     &in automatic mode ... YE or NO'/)
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
420   READ(5,430)ANS
430   FORMAT(A2)
      IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 700
      IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 450
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT
      WRITE (6,410)
440   FORMAT(' Please enter your response again')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
      GOTO 405
450   CONTINUE

C
C     CONTINUES IN AUTOMATIC MODE
C
C
C     PROGRAM IS GOING TO SUMMUP DIRECTLY
C
      XPOS(J) = XS
      ZPOS(J) = ZS
      ANGLE(J) = AS
      GOTO 500
7100  CONTINUE
      CALL OPDISC ('*SVTOR',12)

C     CALL NEWPAG
C
C     THE NEXT (CORRECT) W.S., AFTER THE SELECTED  W.S.
C     (OR WORK STATIONS) ARE POSITIONED
C     TO START WITHIN AUTOMATIC POSITIONING SYSTEM,
C     IS RETRIEVED
C
7110  CONTINUE
      READ (12,30)J,X(J),Y(J),Z(J),FRAME(J)(1:12)
      IF (J.NE.L) GOTO 7110
      IF (J.EQ.L) GOTO 7120
7120  CONTINUE
      XS = XPOS(J)
      ZS = ZPOS(J)
```

```
            AS = ANGLE(J)
      480   CONTINUE

            CALL 1N3D (CESPAC,'CIVILD')
            CALL DRAWIT (CESPAC)
      C
      C     BECAUSE THE NEXT ROUND IS ADDING TO 'K'  ZS=SUMZ
      C


      500   CALL SUMUPZ (J,XSUM,ZSUM,XS,ZS,AS)
            WRITE(6,10)ALPHA
            WRITE(6,10)SELECT
            WRITE (6,520)
      520   FORMAT (' TOTAL VALUE OF -Z- DIMENSION IS'/)
            WRITE (6,540) ZSUM
      540   FORMAT (F10.2)
            WRITE(6,10)DESEL
            WRITE(6,10)GRAPH1

      C
      C     A NEW (NEXT) W.S. IS CONSIDERED
      C


            READ (12,30,END=700)K,X(K),Y(K),Z(K),FNAME(K)(1:12)

            CALL PLACE(K,XSUM,ZSUM,AS,1)
      C
      C     'T' IS THE VERY LAST WORK STATION WHICH IS CLASHING
      C     WITH BUILDING (CIVIL ENG. SPACE/ELEMENT/BOX)
      C     OR IN COLLISION WITH ANOTHER WORK STATION
      C

            CALL  COLLCWS (T,CESPAC,RESULT)
      C
      C     ACTIONS WHEN CLASH OR COLLISION OCCURS
      C
            WRITE (6,800)
      800   FORMAT (' RESULT')
            WRITE (6,1000)RESULT
      1000  FORMAT (I8)
            IF (RESULT.EQ.2) GOTO 5000
            IF (RESULT.EQ.3) THEN
            GOTO 5500
            ELSE
            GOTO 4000
            END IF

      4000  CALL BELL
            WRITE (6,10)ALPHA
            WRITE (6,10)SELECT
            WRITE (6,4100)
      4100  FORMAT (' CLASH !!!')
            WRITE (6,4110)FNAME(K)(1:12)
      4110  FORMAT (2X,A12)


            WRITE (6,10)DESEL
            WRITE (6,10)GRAPH1
```

```
      WRITE(6,4200)
4200  FORMAT (' Do you wish to see the scene of the clash')
4250  READ (5,4300)ANS
4300  FORMAT (A2)
      IF (ANS.EQ.'NO'.OR.ANS.EQ.'N') GOTO 6100
      IF (ANS.EQ.'YE'.OR.ANS.EQ.'Y') GOTO 6000
      WRITE (6,4400)
4400  FORMAT (' Please enter your response again - use capitals')
      GOTO 4250
5000  CONTINUE
      WRITE (6,5200)
5200  FORMAT (' TOUCH ! ')
5500  CONTINUE
C     CALL DRAWIT (T)
      CALL DRAWIT (CESPAC)
      WRITE (6,10)ALPHA
      WRITE (6,10)SELECT
      WRITE (6,3100)
3100  FORMAT(' LAYOUT ACCEPTABLE')
      WRITE (6,10)DESEL
      WRITE (6,10)GRAPHI
C
C     'J' IS REPLACED BY 'K'
C
      J = K
      XPOS(K) = XSUM
      ZPOS(K) = ZSUM
      ANGLE(K) = AS
      ZS = ZSUM
5800  CONTINUE
      GOTO 480
6000  CONTINUE
      CALL NEWPAG
      CALL DRAWIT(T)
      CALL DRAWIT (CESPAC)
6100  CONTINUE
      WRITE (6,10)ALPHA
      WRITE (6,10)SELECT
      WRITE (6,6120)
6120  FORMAT (' DO YOU WISH TO RE-POSIT THE CLASHING W.S. ONLY'/
     &'...YES,NO...If NO you can reposition any No.of W.S.')
      WRITE (6,10)DESEL
      WRITE (6,10)GRAPHI
6130  READ (5,6140)ANS
6140  FORMAT (A2)
      IF (ANS.EQ.'NO'.OR.ANS.EQ.'N') GOTO 7000
      IF (ANS.EQ.'YE'.OR.ANS.EQ.'Y') GOTO 6200
      WRITE (6,6150)
6150  FORMAT (' Please enter your response again - use capitals')
      GOTO 6130
6200  CONTINUE
C
C     THE CLASHING WORK STATION WILL BE REPOSITIONED
C
      J = K
```

```
6500  GOTO 150
700   CONTINUE
C
C     POSITION OF THE LAST WORK STATION IS RECORDED
C

      CALL OPDISC ('WSPOSA',11)
      DO 3300 L = 1,76
      IF (XPOS(L).EQ.999.0.AND.ZPOS(L).EQ.999.0) GOTC 3300
      WRITE (11,3200) L,XPOS(L),ZPOS(L),ANGLE(L),FNAME(L)(1:12)
3200  FORMAT (I5,3F8.2,A12)

3300  CONTINUE
      CALL CLDISC ('WSPOSA',11)
      CALL CLDISC ('WSVTOR',12)
C
C    FOR A NEET FINAL PRENTATION THE LEYOUT IS REDRAWN
C    WITH DETAILES OF WORK STATIONS RETRIEVED
C
      CALL NEWPAG
      CALL PRESIT (NWS)
C     CALL PRESITDET (NWS)

C
C     FINAL DECISSION IS MADE REGARDING CONTINUATION
C     OR STOPING THE PROGRAM
C
      WRITE (6,10)ALPHA
      WRITE (6,10)SELECT
      WRITE(6,3320)
3320  FORMAT (' Do you wish to reoraw the layout?...YES,NO..'/
     &' If NO is typed, the session is over')
      WRITE (6,10)DESEL
      WRITE (6,10)GRAPHI
3360  READ (5,3330)ANS
3330  FORMAT (A2)
      IF (ANS.EQ.'NO'.OR.ANS.EQ.'N') GOTO 3400
      IF (ANS.EQ.'YE'.OR.ANS.EQ.'Y') GOTO 15
      WRITE (6,3340)
      WRITE (6,10)ALPHA
      WRITE (6,10)SELECT
3340  FORMAT (' Please enter your response again - use capitals')
      WRITE (6,10)DESEL
      WRITE (6,10)GRAPHI
      GOTO 3360

3400  CONTINUE
      RETURN
      END


C...
      SUBROUTINE JOY2 (J,PICPLA,DISTNC,K,XS,ZS,AS)
C
C     SUBROUTINE "JOY2" IS A MODIFIED SUBROUTINE JOYS1
C     WHICH WILL ALLOWE TO POSITION ONLY ONE WORK STATION
C     IN TIME.
C     THIS IS BECAUSE OF THE 'ZPOS' DIMENSION WHICH HAS
C     TO BE SUMMED.
```

```
C
C
      REAL X,Y,Z,XPOS,ZPOS,ANGLE
      REAL P(500),R(2000),O(2000),T(2000),G(2000),V(2000)
      REAL CESPAC(10000)
      INTEGER NWS,ANS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME(77)
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME
      CHARACTER*12 WSNAME
      DATA X,Y,Z/231*999.0/
      DATA XPOS,ZPOS/154*999.0/
      DATA ANGLE/77*0.0/
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/
C
      WRITE(6,10)ALPHA
10    FORMAT('+',A2,$)
      WRITE(6,10)SELECT
      WRITE (6,50)
50    FORMAT (' You are now in the Manual ..to..Auto Mode'/)

70    CONTINUE
C     CHANGE OF LAYOUT IS CONSIDERED
      WRITE(6,90)
90    FORMAT(' Do you wish to re-POSITION the work Station...YE or NO')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
100   READ(5,110)ANS
110   FORMAT(A2)
      IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 250
      IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 150
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT
      WRITE (6,120)
120   FORMAT(' Please enter your response again')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
      GOTO 70
150   CONTINUE
153   CONTINUE
      CONTINUE
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT
      WRITE (6,155)
155   FORMAT (' Please POSITION the W.S. by cross-hairs...')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
C
C     1st movement POSIT the right bottom corner..press spacer..
C     2nd movement POSIT/turns the w.s. around this corner..
C
C     press spacer.
C
160   CALL BELL
C     CALL PLIT(3.0,-5.0,3)
C
```

```
C     FIRST WORK STATION VOLUME IS READ AUTOMATICALLY
C     VIA SUBROUTINE "POSIT" (AREA LABLE 25-30)...J...N !
C     REANGLE(J)ON IS TO HAVE FIRST W.S. OF A GROUP OF MACHINES
C     READY FOR AUTOMATIC READING.
C
      CALL BOX(P,X(J),Y(J),Z(J))
      CALL SCREEN(ICHAR,X1,Y1)
      CALL SCREEN(ICHAR,X2,Y2)
      CALL NEWPAG
C     CALL BELL
      CALL OPDISC('MESDIM',10)
      NLX   =DIN('NLX    ')
      NLY   =DIN('NLY    ')
      NLZ   =DIN('NLZ    ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('MESDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
      CALL IN3D (CESPAC,'CIVILO')
      CALL DRAWIT (CESPAC)
      AS = ATAN2(Y2-Y1,X2-X1)*180.0/3.14159265
      XS = Y1*DISTNC/PICPLA
      ZS = X1*DISTNC/PICPLA
      CALL BOX(P,X(J),Y(J),Z(J))

      CALL HERSH(FNAME(J)(1:12),6,2,60.0,0)
      CALL TRANSP(0,T)
      CALL TURN3D(T,270.0,0.0,0.0,1,G)
      CALL JOIN(P,G)
      WSNAME = FNAME(J)
      CALL IN3D (V,WSNAME)
      CALL JOIN (G,V)
      CALL TURN3D(V,AS,0.0,0.0,2,R)
      CALL SHIFT3(R,XS,0.0,ZS)
      CALL DRAWIT (R)
C     CALL DRAW3D(V,1.0,XS,0.0,ZS,1)
180   CONTINUE
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT

      WRITE (6,200)
200   FORMAT (' Is the POSITion of W.S. according to your wish...
     &YE or NO'/)
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
210   READ(5,220)ANS
220   FORMAT(A2)
      IF(ANS.EQ.'NO'.OR.ANS.EQ.'N')GOTO 153
      IF(ANS.EQ.'YE'.OR.ANS.EQ.'Y')GOTO 250
      WRITE(6,10)ALPHA
      WRITE(6,10)SELECT
      WRITE (6,230)
230   FORMAT(' Please enter your response again')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
      GOTO 210
250   CONTINUE
      XPOS(N) = XS
      ZPOS(N) = ZS
      ANGLE(N) = AS
c
```

```
C       POSITION OF THE WORK STATION POSITIONED VIA JOYSTICK
C       IS RECORDED/FILED IN 'WSPOSA',11
C
        CALL OPDISC('WSPOSA',11)
        DO 290 N = 1,76
        IF(XPOS(N).EQ.999.0.AND.ZPOS(N).EQ.999.0)GOTO 290
        WRITE(10,270)N,XPOS(N),ZPOS(N),ANGLE(N),FNAME(N)(1:12)
  270   FORMAT(I5,3F10.2,A12)
  290   CONTINUE
        CALL CLDISC('WSPOSA',11)

        RETURN
        END

C
C
C...
        SUBROUTINE SUMUPZ (J,SUMX,SUMZ,XS,ZS,AS)
C
C        THIS SUBROUTINE IS CALCULATING THE TOTAL "Z" DIMENSION
C

        REAL X,Y,Z,XPOS,ZPOS,ANGLE
        REAL XS,ZS,AS
        REAL P(500), W(7000), SUMX, SUMZ
        INTEGER J
        COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
       &FNAME(77)
        INTEGER SELECT,DESEL, ALPHA,GRAPH1
        CHARACTER*12 FNAME
        CHARACTER*12 WSNAME
        DATA SELECT/"40033/
        DATA DESEL/"40433/
        DATA ALPHA/"30/
        DATA GRAPH1/"35/

        WRITE(6,10)ALPHA
   10   FORMAT('+',A2,$)
        WRITE(6,10)SELECT
        WRITE (6,20)
   20   FORMAT (' YOU ARE NOW IN SUMUPZ SUBROUTINE
       &to activate press return/new line once! '/)
        WRITE(6,10)DESEL
        WRITE(6,10)GRAPH1
C
C       "ZPOS(J)"  SUM UP
C       SUM UP THE "Z" DIMENSIONS OF ALL PREVIOUS WORK STATIONS
C       BECAUSE THE WORK STATION MODULE VOLUME AND WORK STATION
C       DETAILED SHOULD BE CONSIDERED BOTH ARE TAKEN INTO
C       AN ACCOUNT.
C
C
        CALL BOX (P,X(J),Y(J),Z(J))
        WSNAME=FNAME(J)
        CALL IN3D(W,WSNAME)
C        write(*,*)' w',w(4),w(5),w(6)
C        write(*,*)'  ',w(7),w(8),w(9)
        CALL JOIN (P,W)
        D = DEPTH(W)
C       write(*,*)' p',p(4),p(5),p(6)
```

```
C       write(*,*)'  ',p(7),p(8),p(9)
C
C       BECAUSE OF TURNING DURING THE POSITIONING
C       THE ANGLE IS CHANGING AND THIS IS CHANGING
C       THE ACTUAL DISTANCE OF THE NEXT WORK STATION
C       POSITION
C       D = D/cosn of the angle
c

        F = D/COS(AS)

C
C       INSTEAD OF THE ORIGINAL ZPOS(J) XPOS(J) IS TAKEN
C       SUMM OF 'Z' DIMENSION
C
C       write(*,*)' zs',zs,' d' ,d
        SUMZ = ZS + F
        SUMX=XS
C        ZS = SUMZ
        RETURN
        END

C...

        SUBROUTINE PLACE (K,XSUM,ZSUM,AS,T)
C
C       (PLACING A NEXT W.S. IN THE DIRECTION 'Z')
C

C       THIS SUBROUTINE IS ACTUALLY PLACING A WORK STATION INTO
C       AN OPTIMUM POSITION RELATED TO OTHER SPACES (W.S. VOLUMES
C       CIVIL ENG SPACE AND M.H. SPACE). NO INTERVENTION OF
C       THE USER IS NEEDED.

        REAL X,Y,Z,XPOS,ZPOS,ANGLE
        REAL XSUM,ZSUM,AS
        REAL P(500), W(7000), T(7300)
        INTEGER NWS,K
        COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
       &FNAME(77)
        INTEGER SELECT,DESEL, ALPHA,GRAPHI
        CHARACTER*12 FNAME
        CHARACTER*12 WSNAME
        DATA X,Y,Z/231*999.0/
        DATA XPOS,ZPOS/154*999.0/
        DATA ANGLE/77*0.0/
        DATA SELECT/"40033/
        DATA DESEL/"40433/
        DATA ALPHA/"30/
        DATA GRAPHI/"35/

C       CALL BELL
        WRITE(6,10)ALPHA
10      FORMAT('+',A2,$)
        WRITE(6,10)SELECT
        WRITE (6,20)
20      FORMAT (' YOU ARE NOW IN AUTOMATIC MODE
       &to activate press return/new line once! '/)
        WRITE(6,10)DESEL
        WRITE(6,10)GRAPHI
```

```
C       AFTER THE  SUM UP THE NEXT PLACES THE WORK STATION
C       VOLUME IN AN OPTIMUM POSITION WITH A NEW 'Z' DIMENSION
C       BUT THERE ARE NO CHANGES IN 'X' DIMENSION YET
C
C       CALL BELL
        CALL OPDISC('MESDIM',10)
        NLX   =DIN('NLX    ')
        NLY   =DIN('NLY    ')
        NLZ   =DIN('NLZ    ')
        SPACE =DIN('SPACE ')
        CALL CLDISC('MESDIM',10)
        CALL MESH(NLX,NLY,NLZ,SPACE)

        CALL BOX(P,X(K),Y(K),Z(K))

        WSNAME = FNAME(K)
C
C       DETAILED WORK STATION IS RETRIEVED FROM THE DISC "WSNAME"
C
        CALL IN3D(W,WSNAME)
        CALL JOIN (P,W)
        CALL TURN3D(W,AS,0.0,0.0,Z,T)
        CALL SHIFT3 (T,XSUM,0.0,ZSUM)
        CALL DRAWIT (T)
        RETURN
        END
C...
        SUBROUTINE SIGNAL
300     CONTINUE
        WRITE (6,40)
40      FORMAT (' DIAGNOSTIC !'//)

400     CALL BELL
        WRITE (6,410)
410     FORMAT (' CLASH!!! CORRECTIVE ACTION KINDLY REQUESTED!')

500     CONTINUE
        RETURN
        END
C
C        FOLLOWS SUBROUTINE FOR COLLISION OF THE LAST WORK
C        STATION AND THE BUILDING (CIVIL ENG. SPACE)
C
C...

        SUBROUTINE COLLCWS (WS1,CESPAC,RESULT)
        REAL WS1(7300)

        REAL CESPAC(10000)
        INTEGER RESULT,AREA
C       COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
C      &FNAME(77)

        CHARACTER*12 FNAME
        CHARACTER*12 WSNAME

        INTEGER SELECT,DESEL, ALPHA,GRAPHI
        DATA SELECT/"40033/
        DATA DESEL/"40433/
```

```
      DATA ALPHA/"30/
      DATA GRAPHI/"35/
C
C     FIRST CALL IN CIVIL ENG. SPACE
C
C     CALL IN3D (CESPAC,'CIVILD')


C     FOLLOWS SUBROUTINE FOR CHECKING RESULT
C      OF COLLISION

      WRITE (6,10)ALPHA
10    FORMAT ("+",A2,$)
      WRITE (6,10)SELECT
      WRITE (6,30)
30    FORMAT (" 1 = INSIDE"/" 2 = TOUCH (O.K.!)"/" 3 = OUTSIDE")
      WRITE (6,10)DESEL
      WRITE (6,10)GRAPHI
      CALL INSPAC (WS1,CESPAC,RESULT)
      WRITE (6,100) RESULT
100   FORMAT (I8)


      RETURN
      END
C
C     "INSPAC" IS CONTROLING THE PROCESS IN
C     THE COLLISION FINDING
C
C...
      SUBROUTINE INSPAC (WS1,CESPAC,RESULT)
      REAL WS(1), CESPAC(1), OBJECT(100)
C
C     WS1    = WORK STATION WHICH IS (AS A LAST ONE) POSITIONED
C              IN THE BAY (CIVIL ENG. SPACE)
C     CESPAC = BUILDING (CIVIL ENG. SPACE)
C     OBJECT = IS ANY CIVIL ENG. ELEMENT OF WHICH THE BUILDING
C              CONSIST
C
      INTEGER RESULT, AREA
C     COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
C    &FNAME(77)
C
C     NBLOCK IS GIVEN BY A NUMBER OF PICASO CONTOURS
C     AND IS ACTUALLY GIVING (BY ANALYSIS) A NUMBER
C     OF OBJECTS OF WHICH THE BUILDING CONSISTS
C     AND IS LIMITING THE NUMBER OF LOOPS
C
      NBLOCK = CESPAC(2)/6.0
      DO 100 N = 1, NBLOCK
      CALL ABOX (CESPAC, N, OBJECT)
      CALL COLISN (WS1, OBJECT, RESULT, AREA)
      WRITE (6,80) RESULT
80    FORMAT (I6)
      IF (RESULT.EQ.1) RETURN
100   CONTINUE

      RETURN
      END
C
```

```
C      "ABOX" IS RETRIEVING FORM CIVIL ENGINEERING
C      DRAWING INDIVIDUAL CIVIL ENGINEERING SPACES(ELEMENTS)
C      ONE SPACE(ELEMENT - ACTUALLY THE "NTH",NTH) IN TIME
C...
       SUBROUTINE ABOX (CESPAC, NTH, OBJECT)
       REAL CESPAC(1), OBJECT(1), SHAPE(100)
       INTEGER FROM, TO
C      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
C     &FRAME(77)

       IF (NTH.LT.1) THEN
       GOTO 200
       ELSE IF (NTH.GT.100) THEN
       GOTO 250
       ELSE
       GOTO 270
       END IF
200    CONTINUE
C
       WRITE (6,310)
310    FORMAT('DIAGNOSTIC - WRONG READING 1')
250    WRITE (6,320)
320    FORMAT('DIAGNOSTIC - TOO BIG -ERROR 2')
C
C      READING OF CONTOURS OF INDIVIDUAL OBJECTS
C
270    CONTINUE

       FROM = (NTH - 1) * 6 + 1
       TO   = FROM + 5

       DO 10 N = FROM, TO
C
C      THE INDIVIDUAL SHAPE IS EXTRACTED
C
       CALL EXTSH (CESPAC, N, SHAPE)
       IF (N.EQ.FROM) CALL COPY (SHAPE,OBJECT)
       IF (N.NE.FROM) CALL JOIN (SHAPE,OBJECT)
10     CONTINUE
       RETURN
       END
C...
C...

       SUBROUTINE COLISN (WS1,OBJECT,RESULT,AREA)
       REAL WS1(1),OBJECT(100)
       INTEGER RESULT,AREA
C      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
C     &FRAME(77)
       INTEGER SELECT,DESEL, ALPHA,GRAPHI
       DATA SELECT/"40033/
       DATA DESEL/"40433/
       DATA ALPHA/"30/
       DATA GRAPHI/"35/

       WRITE (6,10) ALPHA
10     FORMAT ('+',A2,$)
       WRITE (6,10) SELECT
       CALL HULL3D (WS1,XMIN1,XMAX1,YMIN1,YMAX1,ZMIN1,ZMAX1)
       CALL HULL3D (OBJECT,XMIN2,XMAX2,YMIN2,YMAX2,ZMIN2,ZMAX2)
```

```
      RESULT = 3
      WRITE (6,30) RESULT
30    FORMAT (I8)
C     AREA = 1
C
C     HORIZONTAL PLANE IN AREA 'X' IS TESTED (AREA=1)
C
      IF (XMIN2.EQ.XMAX1.OR.XMAX2.EQ.XMIN1) GOTO 100
C     CONDITION OF OUTSIDE ... 3 IS CONSIDERED
      IF (XMAX2.LT.XMIN1.OR.XMIN2.GT.XMAX1) RETURN
      GOTO 150
100   IF ((YMIN2.LE.YMAX1.AND.YMAX2.GT.YMIN1).OR.
     &(YMAX2.GE.YMIN1.AND.YMIN2.GT.YMIN1)) GOTO 200
C     CONDITION OUTSIDE ... 3 IS CONSIDERED
150   IF (YMAX2.LT.YMIN1.OR.YMIN2.GT.YMAX1) RETURN
      GOTO 250
C
C     CONDITION IN Z-DIMENSION
C     CONDITION "TOUCH...2" IS CONSIDERED
C
200   IF ((ZMIN2.LE.ZMAX1.AND.ZMAX2.GT.ZMIN1) .OR.
     &(ZMAX2.GE.ZMIN1.AND.ZMIN2.GT.ZMIN1)) GOTO 300
250   IF (ZMAX2.LT.ZMIN1.OR.ZMIN2.GT.ZMAX1) RETURN
      RESULT = 1
      WRITE (6,260) RESULT
260   FORMAT (I8)
      RETURN
300   RESULT = 2
      WRITE (6,320) RESULT
320   FORMAT (I8)

      WRITE (6,10)DESEL
      WRITE (6,10)GRAPHI
      RETURN
      END
C....
C     END OF PROGRAM "COLLCWS1.FOR"
C
C....
C...
      SUBROUTINE JOYST(NWS,PICPLA,DISTNC,J)
      REAL P(500),R(2000),Q(2000),T(2000),U(2000)
      REAL V(2000), CESPAC(10000)
      INTEGER NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME(77)
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME
      CHARACTER*12 WSNAME

      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/

60    CALL BELL
      CALL PLIT(3.0,-5.0,3)
      WRITE(6,70)ALPHA
70    FORMAT('+',A2,$)
```

```
      WRITE(6,70)SELECT
      WRITE(6,80)
80    FORMAT(' Which work Station.;to start from? Type Tag No...'/
     &' To end ...type "END"')
      WRITE(6,70)DESEL
      WRITE(6,70)GRAPHI

90    CONTINUE
      READ (5,100) WSNAME
100   FORMAT (A12)
      WRITE (6,110) WSNAME
110   FORMAT (1X,A12)
      IF (WSNAME(1:3).EQ.'END') GOTO 190

      DO 120 J = 1,76
      IF (WSNAME.EQ.FNAME(J)(1:12)) GOTO 140
120   CONTINUE

      WRITE (6,130)
130   FORMAT (' Please enter your TAG NO exactly again')
      GOTO 90

C
C
140   CALL BOX(P,X(J),Y(J),Z(J))
      CALL SCREEN(ICHAR,X1,Y1)
      CALL SCREEN(ICHAR,X2,Y2)
      CALL NEWPAG
      CALL BELL
      CALL OPDISC('MESDIM',10)
      NLX   =DIN('NLX    ')
      NLY   =DIN('NLY    ')
      NLZ   =DIN('NLZ    ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('MESDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
      CALL IN3D (CESPAC,'CIVILD')
      CALL DRAWIT (CESPAC)
      ANGLE(J) = ATAN2(Y2-Y1,X2-X1)*180.0/3.14159265
      XPOS(J) = Y1*DISTNC/PICPLA
      ZPOS(J) = X1*DISTNC/PICPLA
      DO 180 M = 1,76
      CALL BOX(P,X(M),Y(M),Z(M))
      XWORK = XPOS(M)
      ZWORK = ZPOS(M)
      IF(XWORK.EQ.999.0.AND.ZWORK.EQ.999.0)GOTO 180
      CALL HERSH(FNAME(M)(1:12),6,2,60.0,Q)
      CALL TRANSP(Q,T)
      CALL TURN3D(T,270.0,0.0,0.0,1,U)
      CALL JOIN(P,U)
      CALL IN3D (V,FNAME(M))
      CALL JOIN (U,V)

      CALL TURN3D(V,ANGLE(M),0.0,0.0,2,R)
      CALL SHIFT3 (R,XWORK,0.0,ZWORK)
      CALL DRAWIT (R)
C     CALL DRAW3D(U,1.0,XWORK,0.0,ZWORK,1)
180   CONTINUE
      GOTO 60
190   CONTINUE
```

```
      CALL OPDISC('WSPOSA',11)
      DO 200 M = 1,76
      IF(XPOS(M).EQ.999.0.AND.ZPOS(M).EQ.999.0)GOTO 200
      WRITE(10,210)M,XPOS(M),ZPOS(M),ANGLE(M),FNAME(M)(1:12)
210   FORMAT(I5,3F10.2,A12)
200   CONTINUE
      CALL CLDISC('WSPOSA',11)
250   RETURN
      END
C...
      SUBROUTINE PRESITDET (NWS)
C
C     THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION
C     WITH DETAILED WORK STATIONS DRAWN

C
      REAL P(500),R(2000),Q(2000),T(2000),U(2000)
      REAL CESPAC(10000),V(2000)
      INTEGER NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME(77)
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME
      CHARACTER*12 WSNAME
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/
C     PRINTING THE PRESENT SITUATION OF LAYOUT DEVELOPMENT
      WRITE(6,10)ALPHA
10    FORMAT('+',A2,$)
      WRITE(6,10)SELECT
      WRITE(6,20)
20    FORMAT(' LAYOUT...The existing situation of development')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
      CALL BELL
      CALL OPDISC('MESDIM',10)
      NLX   =DIM('NLX    ')
      NLY   =DIM('NLY    ')
      NLZ   =DIM('NLZ    ')
      SPACE =DIM('SPACE  ')
      CALL CLDISC('MESDIM',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
C
C     BUILDING IS CALLED IN
C
      CALL IN3D (CESPAC,'CIVILD')
      CALL DRAWIT (CESPAC)
      CALL OPDISC('WSVTOR',12)
40    READ(12,60,END=50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
      CALL OPDISC('WSPOSA',11)
50    READ(11,60,END=90)J,XPOS(J),ZPOS(J),ANGLE(J),FNAME(J)(1:12)
60    FORMAT(I5,3F8.2,A12)
      CALL BOX(P,X(J),Y(J),Z(J))
      XWORK = XPOS(J)
      ZWORK = ZPOS(J)
      CALL TURN3D(P,ANGLE(J),0.0,0.0,2,R)
      CALL HERSH(FNAME(J)(1:12),6,2,60.0,Q)
      CALL TRANSP(Q,T)
```

```
              CALL TURN3D(T,270.0,0.0,0.0,1,U)
              CALL JOIN(R,U)
              WSNAME = FNAME(J)
              CALL IN3D (V,WSNAME)
              CALL JOIN(U,V)
              CALL SHIFT3 (V,XWORK,0.0,ZWORK)
              CALL DRAWIT (V)
C             CALL DRAW3D(U,1.0,XWORK,0.0,ZWORK,1)
              GOTO 40
90            CONTINUE
              CALL CLDISC('WSPOSA',11)
              CALL CLDISC('WSVTOR',12)


              RETURN
              END
C...
C...
C....
C             FILE UNDER 'POSCLASH4.FOR'
```

50

```
7777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777
77777777777777777777777777777   MIDDLESEX POLYTECHNIC VAXB 11/785   7777777777777777777777777777777
7777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777

BBBBBBBB      OOOOOO     BBBBBBBB       11
BBBBBBBB      OOOOOO     BBBBBBBB       11
BB      BB  OO      OO   BB      BB   1111
BB      BB  OO      OO   BB      BB   1111
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BBBBBBBB    OO      OO   BBBBBBBB       11
BBBBBBBB    OO      OO   BBBBBBBB       11
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BB      BB  OO      OO   BB      BB     11
BBBBBBBB      OOOOOO     BBBBBBBB     111111
BBBBBBBB      OOOOOO     BBBBBBBB     111111

DDDD     III    SSSS   PPPP    L        AAA    Y   Y
D   D     I    S       P   P   L       A   A   Y   Y
D   D     I    S       P   P   L       A   A    Y Y
D   D     I     SSS    PPPP    L       A   A     Y
D   D     I        S   P       L       AAAAA     Y
D   D     I        S   P       L       A   A     Y
DDDD     III   SSSS    P       LLLLL   A   A     Y


     J   OOO   BBBB          1     1    666    666
     J  O   O  B   B        11    11   6      6
     J  O   O  B   B         1     1   6      6
     J  O   O  BBBB          1     1   6666   6666
 J   J  O   O  B   B         1     1   6   6  6   6
 J   J  O   O  B   B         1     1   6   6  6   6
  JJJ    OOO   BBBB         111   111   666    666

66) queued to SYS$PRINT on 9-NOV-1987 12:15 by user BOB1, UIC [RESM0012,BOB1], under account RES
 printer _LPA0: on 9-NOV-1987 12:15 from queue LPA0.

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7777777777777777777777  Digital Equipment Corporation - VAX/VMS Version V4.5  77777777777777777
7777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777777
```

```
C       'DISPLAY.FOR'
C       THIS IS A PROGRAM FOR DISPLAY OF WHOLE DESIGNES
C       SCENE TO ENABLE THE USER TO OBSERVE THE LAYOUT
C       FROM ANY REQUESTED POSITION
C
C
C
        INTEGER NWS
        COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
       &FNAME(77)
        REAL P(500),R(2000),Q(2000),T(2000),U(2000)
        REAL CESPAC(10000)
        INTEGER SELECT,DESEL,ALPHA,GRAPH1
        CHARACTER*12 FNAME
        CHARACTER*12 WSNAME
        DATA SELECT/"40033/
        DATA DESEL/"40433/
        DATA ALPHA/"30/
        DATA GRAPH1/"35/
        DATA XPOS,ZPOS/154*999.0/
        DATA ANGLE/77*0.0/
        CALL START
C       CALL FACTOR(1.0)
        CALL FORMAT (84.1,59.4)
        CALL FRAME(-55.0,29.0,-35.0,20.0)


3       FORMAT('Program for display of Industr. bay in required
       & elevation with detailed work Stations')
        WRITE(6,5)ALPHA
5       FORMAT(A2)
        WRITE(6,5)SELECT
        WRITE(6,3)
        WRITE(6,5)DESEL
        WRITE(6,5)GRAPH1
        WRITE(6,10)
10      FORMAT('Please enter the DISTANCE, ROTATION & ELEVATION')
        READ(5,*) DISTNC, ROTATN, ELEVTN
        WRITE(6,20)
20      FORMAT ('Please enter the PICPLA(ZOOM) FACTOR')
        READ(5,*) ZOOM
        CALL NEWPAG
        CALL BELL
        CONTINUE
        CALL PEYE (0.0,0.0,0.0,DISTNC,ROTATN,ELEVTN)
        CALL PLANE (ZOOM)
C       CALL MESH(NLX,NLY,NLZ,SPACE)
        CALL OPDISC('WSVOLD',10)
        NWS=1
50      READ(10,70,END=90)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
70      FORMAT(I5,3F8.2,A12)
        NWS=NWS+1
        GOTO 50
90      CALL CLDISC('WSVOLD',10)
        NWS = NWS-1
        CALL PRESIT (NWS)

        CALL GCLOSE
        CALL FINISH
        STOP
```

```
      END
C...
      SUBROUTINE PRESIT (NWS)
C
C     THIS IS A SUBROUTINE FOR SHOWING THE PRESENT SITUATION
C
      REAL P(500),R(6000),G(2000),T(2000),U(2000),V(5000)
      REAL CESPAC(10000)
      INTEGER NWS
      COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
     &FNAME(77)
      INTEGER SELECT,DESEL, ALPHA,GRAPHI
      CHARACTER*12 FNAME
      CHARACTER*12 WSNAME
      DATA SELECT/"40033/
      DATA DESEL/"40433/
      DATA ALPHA/"30/
      DATA GRAPHI/"35/
C     PRINTING THE PRESENT SITUATION OF LAYOUT DEVELOPMENT
      WRITE(6,10)ALPHA
10    FORMAT('+',A2,S)
      WRITE(6,10)SELECT
      WRITE(6,20)
20    FORMAT(' LAYOUT...The existing situation of development')
      WRITE(6,10)DESEL
      WRITE(6,10)GRAPHI
      CALL BELL
      CALL OPDISC('MESDIR',10)
      NLX   =DIN('NLX   ')
      NLY   =DIN('NLY   ')
      NLZ   =DIN('NLZ   ')
      SPACE =DIN('SPACE ')
      CALL CLDISC('MESDIR',10)
      CALL MESH(NLX,NLY,NLZ,SPACE)
C
C     BUILDING IS CALLED IN
C
      CALL IN3D (CESPAC,'CIVILD')
      CALL DRAWIT (CESPAC)
      CALL OPDISC('WSVTOR',12)
40    READ(12,60,END=50)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
      CALL OPDISC('WSPOSA',11)
50    READ(11,60,END=90)J,XPOS(J),ZPOS(J),ANGLE(J),FNAME(J)(1:12)
60    FORMAT(I5,3F8.2,A12)
      CALL BOX(P,X(J),Y(J),Z(J))
      WSNAME = FNAME(J)
      XWORK = XPOS(J)
      ZWORK = ZPOS(J)
      CALL HERSH(FNAME(J)(1:12),6,2,60.0,0)
      CALL TRANSP(G,T)
      CALL TURN3D(T,270.0,0.0,0.0,1,U)
      CALL JOIN(P,U)
      CALL IN3D(V,WSNAME)
      CALL JOIN(U,V)
      CALL TURN3D(V,ANGLE(J),0.0,0.0,2,R)
      CALL SHIFT3 (R,XWORK,0.0,ZWORK)
      CALL DRAWIT (R)
C     CALL DRAW3D(U,1.0,XWORK,0.0,ZWORK,1)
      GOTO 40
90    CONTINUE
```

```
      CALL CLDISC('*SPOSA',11)
      CALL CLDISC('*SVTOR',12)
      RETURN
      END
C
C...
      SUBROUTINE MESH(NLX,NLY,NLZ,SPACE)
      REAL A(1000)
      CALL GRIL3D(A,NLX,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLY,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLZ,.0,.0,.0,.0,FLOAT(NLY-1)*SPACE,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLY,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,.0,SPACE,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLX,.0,.0,.0,.0,.0,FLOAT(NLZ-1)*SPACE,SPACE,.0,.0)
      CALL DRAWIT(A)
      CALL GRIL3D(A,NLZ,.0,.0,.0,FLOAT(NLX-1)*SPACE,.0,.0,.0,.0,SPACE)
      CALL DRAWIT(A)
      RETURN
      END
C...
C...
C...
C...
C
C...
C     FILE UNDER 'DISPLAY'
```

54

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9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
9999999999999999999999999999999999  MIDDLESEX POLYTECHNIC VAXB 11/785   9999999999999999999999999
9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999

        BBBBBBBB       000000     BBBBBBBB        11
        BBBBBBBB       000000     BBBBBBBB        11
        BB      BB   00      00   BB      BB    1111
        BB      BB   00      00   BB      BB    1111
        BB      BB   00      00   BB      BB      11
        BB      BB   00      00   BB      BB      11
        BBBBBBBB     00      00   BBBBBBBB        11
        BBBBBBBB     00      00   BBBBBBBB        11
        BB      BB   00      00   BB      BB      11
        BB      BB   00      00   BB      BB      11
        BB      BB   00      00   BB      BB      11
        BB      BB   00      00   BB      BB      11
        BBBBBBBB       000000     BBBBBBBB      111111
        BBBBBBBB       000000     BBBBBBBB      111111

            M   M  FFFFF  EEEEE  EEEEE  DDDD
            MM MM  F      E      E      D   D
            M M M  F      E      E      D   D
            M   M  FFFF   EEEE   EEEE   D   D
            M   M  F      E      E      D   D
            M   M  F      E      E      D   D
            M   M  F      EEEEE  EEEEE  DDDD


            J   OOO   BBBB            1      1     666   7777
            J  O   O  B   B          11     11    6         7
            J  O   O  B   B           1      1    6         7
            J  O   O  BBBB            1      1    6666     7
        J   J  O   O  B   B           1      1    6   6   7
        J   J  O   O  B   B           1      1    6   6  7
         JJJ    OOO   BBBB           111    111    666   7
```

) queued to SYS$PRINT on 9-NOV-1987 12:16 by user BOB1, UIC [RESM0012,BOB1], under account RESM(
ter _LPA0: on 9-NOV-1987 12:17 from queue LPA0.

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9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
9999999999999999999999  Digital Equipment Corporation - VAX/VMS Version V4.5  99999999999999999
9999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999999
```

```
C      THIS IS A MANUAL FEED PROGRAM "MFEED.FOR"
C      FEEDING INFORMATION ABOUT POSITION OF WORK STATICN
C      ACCORDING TO TECHNOLOGICAL ORDER/LINE
C
C       THE PROGRAM IS ALSO SIMULATING THE DR. CARRIES
C       PROGRAM FOR TECHNOLOGICAL POSITIONING OF WORK STATIONS

C       THE PROGRAM IS FEEDING INFORMATION INTO A FILE 'TECHORD'
C       (IN TECH. LINE ...1,2,3,4, ECT...!!!)
C


C       FROM THIS DISK THE INFORMATION ARE FEAD INTO THE
C       AUTOMATIC POSITIONING PROGRAM 'POSCLASH'
C
C

       INTEGER ANS
       CHARACTER *12 WSNAME (200),WS
C      CALL START
C      OUTPUT OF EXISTING DATA FILE
C      THE LINE IS NOT CHANGING (MUST REMAIN IN A TECHNOLOGICAL
C      ORDER / IN A LINE)
C      INFORMATION HAS TO BE FED IN FORMAT line No. comma Tag.No.
C

 5     CONTINUE
       WRITE (6,10)
 10    FORMAT (' LIST OF M/C AND EQUIPMENT IN TECHNOLOGICAL ORDER'//)
       WRITE (6,20) ' Line', 'Work Stn Number'
 20    FORMAT (A5,1X,A18)
 50    CONTINUE
       CALL OPDISC ('TECHORD',11)
 60    CONTINUE
       READ (11,130,END=135) N,WSNAME(N)(1:12)
 130   FORMAT (I5,A12)
       WRITE (6,132) N,WSNAME(N)(1:12)
 132   FORMAT (I5,2X,A12)

       GOTO 60
 135   WRITE(6,137)
 137   FORMAT (' THERE IS NOTHING MORE IN THE FILE'/)
       CALL CLDISC ('TECHORD',11)
C
C      EXTENDING THE FILE
C
 138   WRITE (6,140)
 140   FORMAT (/' Do you wish to extend or change the file - YE or NO'/)
       READ (5,150)ANS
 150   FORMAT (A2)
       IF (ANS.EQ.'NO'.OR.ANS.EQ.'N') GOTO 500
       IF (ANS.EQ.'YE'.OR.ANS.EQ.'Y') GOTO 170
C
C      ERROR MESSAGE
C
       WRITE(6,160)
 160   FORMAT (' Please enter your response again! Use CAPITALS!')
       GOTO 138
C
C      EXTENDING THE FILE
```

```
      C
      170  CONTINUE
           WRITE (6,172)
      172  FORMAT (' To run program requested type the prefix letter'/
          &' for adding a new Work Station at the end type _A_'/
          &' for inserting  Work Station above a W.S. type _I_'/
          &' for deleting any Work Station type _R_'/)
           READ (5,174) ACTION
      174  FORMAT (A1)
           IF (ACTION.EQ.'A') GO TO 175
           IF (ACTION.EQ.'I') GO TO 300
           IF (ACTION.EQ.'R') GO TO 400
           WRITE (5,160)
           GO TO 170
      175  CONTINUE
      C
      C    FEEDING IN INFORMATION ABOUT THE POSIT OF W.S. LINE OR
      C    ADDING A NEW WORK STATION AT THE END OF LINE
      C    (ADDING TO THE LINE  EX: ...3,4,5,...ADDING 6,7,8 ETC)
      C
           WRITE (6,180)
      180  FORMAT(' Please enter line No. and W.S.No to end type 200'/)
           READ (5,130) N,WSNAME(N)(1:12)
           IF (N.EQ.200) GOTO 210
      C
      C    OUTPUT OF THE LATEST DATA TO DICS AND TERMINAL
      C
           CALL OPDISC ('TECHORD',11)
      190  READ (11,130,END=200)I,WSNAME(I)(1:12)
           GOTO 190
      200  WRITE(11,130)N,WSNAME(N)(1:12)
           CALL CLDISC ('TECHORD',11)
           GO TO 175
      210  CONTINUE
      C
      C    PRINT THE DEVELOPED LIST OF W.S. ON THE VDU
      C
           GO TO 5
      C
      C    INSERTING A NEW W.S. INTO THE EXISTING LINE
      C
      300  CONTINUE
           CALL OPDISC ('TEMP.DAT',10)
           CALL OPDISC ('TECHORD',11)
           WRITE (6,180)
           READ (5,130) N,WS(1:12)
      310  READ (11,130,END=330)I,WSNAME(I)(1:12)
           IF(N.NE.I) GO TO 320
           WRITE(10,130)N,WS
      320  J=I
           IF (I.GE.N) J=J+1
           WRITE (10,130) J,WSNAME(I)(1:12)
           GO TO 310
      330  CONTINUE
           CALL CLDISC ('TEMP.DAT',10)
           CLOSE (UNIT=11,DISPOSE='DELETE')
           CALL OPDISC ('TEMP.DAT',10)
           CALL OPDISC ('TECHORD.DAT',11)
      340  READ (10,130,END=350)N,WSNAME(N)(1:12)
           WRITE (11,130) N,WSNAME(N)(1:12)
```

```
      GO TO 340
350   CALL CLDISC ('TECHORD.DAT',11)
      CLOSE (UNIT=10,DISPOSE='DELETE')
      CONTINUE
C
C     PRINT THE DEVELOPED LIST OF W.S. ON THE VDU
C
      GO TO 5
400   CONTINUE
C
C     RETYPING/DELETING AN EXISTING W.S. AND REPOSITIONING
C     THE LINE OF WORK STATION
C
      CALL OPDISC ('TEMP.DAT',10)
      CALL OPDISC ('TECHORD',11)
      WRITE (6,405)
405   FORMAT (' Type position and W.S. which has to be deleted'/)
      READ (5,130) N,WS(1:12)
410   READ (11,130,END=430)K,WSNAME(K)(1:12)
      IF(N.EQ.K) GO TO 410
      J=K
      IF (K.GT.N) J=J-1
      WRITE (10,130) J,WSNAME(K)(1:12)
      GO TO 410
430   CONTINUE
      CALL CLDISC ('TEMP.DAT',10)
      CLOSE (UNIT=11,DISPOSE='DELETE')
      CALL OPDISC ('TEMP.DAT',10)
      CALL OPDISC ('TECHORD.DAT',11)
440   READ (10,130,END=450)N,WSNAME(N)(1:12)
      WRITE (11,130) N,WSNAME(N)(1:12)
      GO TO 440
450   CALL CLDISC ('TECHORD.DAT',11)
      CLOSE (UNIT=10,DISPOSE='DELETE')
      CONTINUE
C
C     PRINT THE DEVELOPED LIST OF W.S. ON THE VDU
C
      GO TO 5
500   CONTINUE
      STOP
      END
C
C
C....
C     FILE 'MFEED'
C
```

58.

```
8888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888
88888888888888888888888888888888  MIDDLESEX POLYTECHNIC VAX8 11/785   8888888888888888888888888888
8888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888
```

```
BBBBBBBB      OOOOOO     88888888       11
BBBBBBBB      OOOOOO     88888888       11
BB      BB  OO      OO  88      88    1111
BB      BB  OO      OO  88      88    1111
BB      BB  OO      OO  88      88      11
BB      BB  OO      OO  88      88      11
BBBBBBBB    OO      OO   88888888       11
BBBBBBBB    OO      OO   88888888       11
BB      BB  OO      OO  88      88      11
BB      BB  OO      OO  88      88      11
BB      BB  OO      OO  88      88      11
BB      BB  OO      OO  88      88      11
BBBBBBBB      OOOOOO     88888888     111111
BBBBBBBB      OOOOOO     88888888     111111

W   W   SSSS  V   V  TTTTT   OOO   TTTTT   OOO
W   W  S      V   V    T    O   O    T    O   O
W   W  S      V   V    T    O   O    T    O   O
W   W   SSS   V   V    T    O   O    T    O   O
W W W      S  V   V    T    O   O    T    O   O
WW WW      S   V V     T    O   O    T    O   O
W   W  SSSS     V      T     OOO     T     OOO
```

```
    J   OOO   BBBB          1      1     666    888
    J  O   O  B   B        11     11    6      8   8
    J  O   O  B   B         1      1    6      8   8
    J  O   O  BBBB          1      1    6666    888
J   J  O   O  B   B         1      1    6   6  8   8
J   J  O   O  B   B         1      1    6   6  8   8
 JJJ    OOO   BBBB         111    111    666    888
```

68) queued to SYS$PRINT on 9-NOV-1987 12:16 by user B081, BIC [RESM0012,B081], under account RE:
printer _LPA0: on 9-NOV-1987 12:16 from queue LPA0.

```
8888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888
888888888888888888888888  Digital Equipment Corporation - VAX/VMS Version V4.5  8888888888888888
8888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888888
```

```
      C     PROGRAM/SUBROUTINE WSVTOTO
      C     (WORK STATION (VOLUMES) TO TECHNOLOGICAL ORDER)
      C
      C     THIS SUBROUTINE IS RETRIEVING WORK STATION REQUESTED
      C     FOR A SUGGESTED PRODUCTION LINE FROM THE 'WSVOLD' FILE
      C     AND REORGANISES THEM IN TECHNOLOGICAL ORDER-LINE(I.E. FOR
      C     PRODUCTION OR PRODUCT ORIENTATED LAYOUT OR GROUP
      C     TECHNOLOGY ORIENTATED LAYOUT).
      C

            REAL X,Y,Z,XPOS,ZPOS,ANGLE
            INTEGER J,K,N
            COMMON/LCWS/X(77),Y(77),Z(77),XPOS(77),ZPOS(77),ANGLE(77),
           &FNAME(77)
            CHARACTER*12 FNAME
            CHARACTER*12 WSNAME(77)

            CALL START

      C
      C     FIRST NAME OF W.S. IN TECHNOLOGICAL ORDER IS RETRIEVED
      C
            CALL OPDISC ('WSVTOR',12)
            CALL OPDISC ('TECHORD',11)
      20    CONTINUE
            READ (11,50,END=400)N,WSNAME(N)(1:12)
      50    FORMAT (I5,A12)

            CONTINUE
            CALL OPDISC ('WSVOLD',10)
      60    CONTINUE
            READ (10,80,END=100)J,X(J),Y(J),Z(J),FNAME(J)(1:12)
      80    FORMAT (I5,3F8.2,A12)

      C
      C     COMPARE LIST OF W.S.VOL. WITH TECHNOLOGICAL ORDER
      C
            IF (WSNAME(N)(1:12).EQ.FNAME(J)(1:12)) GOTO 100
            IF (WSNAME(N)(1:12).NE.FNAME(J)(1:12)) GOTO 90
      90    CONTINUE
            GOTO 60
      100   CONTINUE
            WRITE (12,150) N,X(J),Y(J),Z(J),FNAME(J)(1:12)
      150   FORMAT (I5,3F8.2,A12)
            CALL CLDISC ('WSVOLD',10)

            GOTO 20
      400   CONTINUE
            CALL CLDISC ('TECHORD',11)
            CALL CLDISC ('WSVTOR',12)
      C
      C     READ ALL CREATED LINE OF W.S.VOL. IN TECHNOLOGICAL ORDER
      C
            CALL OPDISC ('WSVTOR',12)

            K = 1
      450   CONTINUE
            READ (12,470,END=550) K,X(K),Y(K),Z(K),FNAME(K)(1:12)
      470   FORMAT (I5,3F8.2,A12)
            WRITE (6,480)K,X(K),Y(K),Z(K),FNAME(K)(1:12)
```

```
 480   FORMAT (I5,3F8.2,1X,A12)
       K = K+1
       GOTO 450
 550   CONTINUE
       CALL CLDISC ('*SVTOR',12)
C      RETURN
       STOP
       END
```

61

```
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000  MIDDLESEX POLYTECHNIC VAXB 11/785   0000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

```
BBBBBBBB      000000     BBBBBBBB        11
BBBBBBBB      000000     BBBBBBBB        11
BB      BB  00      00   BB      BB    1111
BB      BB  00      00   BB      BB    1111
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BBBBBBBB    00      00   BBBBBBBB        11
BBBBBBBB    00      00   BBBBBBBB        11
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BB      BB  00      00   BB      BB      11
BBBBBBBB      000000     BBBBBBBB      111111
BBBBBBBB      000000     BBBBBBBB      111111
```

```
M   M    1     000     000
MM MM   11    0   0   0   0
M M M    1    0  00   0  00
M   M    1    0 0 0   0 0 0
M   M    1    00  0   00  0
M   M    1    0   0   0   0
M   M   111    000     000
```

```
    J   000   BBBB         1      1     666    999
    J  0   0  B   B       11     11    6      9   9
    J  0   0  B   B        1      1    6      9   9
    J  0   0  BBBB         1      1    6666    9999
J   J  0   0  B   B        1      1    6   6      9
J   J  0   0  B   B        1      1    6   6      9
 JJJ    000   BBBB        111    111    666    999
```

queued to SYS$PRINT on 9-NOV-1987 12:17 by user BOB1, UIC [RESM0012,BOB1], under account RESM00:
er _LPA0: on 9-NOV-1987 12:17 from queue LPA0.

```
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000  Digital Equipment Corporation - VAX/VMS Version V4.5  00000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

```
C....,THIS IS PROGRAM "M100.FOR"
C      FOR BASIC CAPACITY CALCULATION FOR FACTORY LAYOUT PLANNIG

C...
       INTEGER ACTION
       WRITE(6,10)
10     FORMAT(' CAFLAP MASTER PROGRAM'/)
C...Functions of the program are:
C...-to enable to enter and run individual programs separately
C...-to chnage sequences/order of execution
C...-to ease interaction between programs
C...
       WRITE(6,20)
20     FORMAT(' MENU of the CAFLP master program'/)
       WRITE(6,110)
110    FORMAT(' A   VOLUME OF MATERIAL HANDLING(VOLMH)')
       WRITE(6,120)
120    FORMAT(' B   NUMBER OF WORK STATIONS (NOWS)')
       WRITE(6,130)
130    FORMAT(' C   MANUFACTURING AREA-in sq.M-(MFAREA)')
       WRITE(6,140)
140    FORMAT(' D   TOTAL LENGTH OF INDUSTRIAL BAY-in M-(BAYLGH)')
       WRITE(6,30)
30     FORMAT(' To run  the program requested type the prefix letter
      &...To finish type XX ')
40     READ(5,50)ACTION
50     FORMAT(A1)
       IF (ACTION.EQ.'A')GOTO 210
       IF (ACTION.EQ.'B')GOTO 220
       IF (ACTION.EQ.'C')GOTO 230
       IF (ACTION.EQ.'D')GOTO 240
       IF (ACTION.EQ.'X')GOTO 280
       WRITE(6,60)
60     FORMAT(' PROGRAM IS NOT SELECTED PLEASE TRY AGAIN')
       GOTO 40
210    CONTINUE
       CALL VOLMH
220    CONTINUE
       CALL NOWS
230    CONTINUE
       CALL MFAREA
240    CONTINUE
       CALL BAYLGH
280    CONTINUE
       STOP
       END
C...
       SUBROUTINE VOLMH
C      FACTORY LAYOUT PLANNING-VOLUME OF MATERIAL HANDLING
C      THE FOLLOWING PROGRAM CALCULATES A VOLUME OF MATERIAL ,W.I.P.
C      AND PRODUCT
C      IN UNIT LOADS(UNL) PASSING TROUGH A FACTORY/INDUSTRIAL BAY
C      THIS PROGRAM IS AN ENTRY PROGRAM
       WRITE(6,10)
10     FORMAT('FACTORY LAYOUT PLANNING-VOLUME OF MATERIAL HANDLING')
C      STEP 1 CALCULATES THE NUMBER OF PARTS PER UNIT LOAD(NPPUNL)
C      VOLUME OF UNIT LOAD IN CUBIC METERS AND VOLUME OF PARTS
C      TO BE MACHINED IN THE BATCH )IN CUBIC METERS IS TO BE DECIUED
C      /CALCULATED BY PRODUCTION DEPT.PRIOR THIS PROGRAM STARTS.
       WRITE(6,20)
```

```
20      FORMAT(' PLEASE ENTER VOLUME OF UNL (VOLUNL)IN CU METERS')
        WRITE(6,30)
30      FORMAT(' PLEASE ENTER VOLUME OF PART(VOLPT) IN CU METERS')
C       VOLUMES TO BE ENTERED VIA KEYBOARD
        READ(5,*)VOLUNL,VOLPT
        NPPUNL=VOLUNL/VOLPT
C       NOW THE SYSTEM WILL PRINT IN COLUMNS THE ABOVE DATA
        WRITE(6,40)
40      FORMAT (4X,'VOLUNL',7X,'VOLPT',8X,'NO PARTS PER UNL')
        WRITE(6,50)VOLUNL,VOLPT,NPPUNL
50      FORMAT(5X,F5.3,3X,F11.8,F16.2)
C
C...    STEP 2 . CALCULATE THE NUMBER OF UNIT LOAD GOING THROUGH BAY
C...    PER YEAR(NOUNLPY),SO WE HAVE TO ENTER PRODUCTION PROGRAMME
C...    IN PARTS PER YEAR(PRODNPROG)
C
        WRITE(6,60)
60      FORMAT(' ENTER THE PRODN PROGRAMME IN PARTS PER YEAR(PPROG)')
        READ (1,*)PPROG
        NUNLPY=PPROG/NPPUNL
        WRITE(6,70)
70      FORMAT(3X,'PRODN PROG.',4X,'NO PARTS PER UNL',9X,'NO UNL PER YR')
        WRITE(6,80)PPROG,NPPUNL,NUNLPY
80      FORMAT(2X,F12.1,3X,F10.1,15X,F12.2)
C       THIS THE BEGINNING OF PROGRAM VOLMH3
C
C       STEP3-CALCULATE NUMBER OF UNIT LOADS GOING THROUGH
C       THE INDUSTRIAL BAY PER HOUR(UNLPH).
C       THE PRODUCTION YEAR HAS NUMBER OF WORKING HOURS GIVEN
C       BY LOCAL CONDITIONS. THIS CAN BE ALSO
C       EXPRESSED BY YEARLY CAPACITY OF A WORK STATION (EFWSH)
C       AVERAGE YEARLY CAPACITY OF A WORK STATION FOR 48HRS WEEK
C       AND ONE SHIFT
C       IS 2000 HOURS(OFCOURSE THIS HAS TO BE AMENDED ACCORDING
C       TO YOUR LOCAL
C       CONDITION...LOCAL CONDITION INCLUDE HOURS CONVENTION
C       (NUMBER OF WORKING HOURS PER WEEK )AND NUMBER OF SHIFTS).
C
        WRITE (1,90)
90      FORMAT(' ENTER PRODUCTION YEAR  NUMBER OF HOURS- (EFWSH)')
        READ(5,*)EFWSH
        UNLPH=NUNLPY/EFWSH
        WRITE(6,100)UNLPH
100     FORMAT(' THE TOTAL NUMBER OF UNIT LOAD GOING THROUGH THE INDUSTRIAL
       & BAY PER HOUR IS',35X,F6.2)
        RETURN
        END
C       THIS THE END OF PROGRAM 'EXVOLMH'
C...

        SUBROUTINE NOWS
C       PROGRAM NUMBER OF WORK STATION NEEDED(NOWS)
C
        WRITE(6,200)
200     FORMAT (' CALCULATE NUMBER OF WORK STATION NEEDED USING UNL')
C
C       THIS CALCULATION HAS AN ADVANTAGE FOR ANY FUTURE
C        CALCULATION BECAUSE
C       OF SPACES CONSIDERATION(PRODUCT SPACES ARE ALWAYS
C       CALCULATED FROM UNIT LOADS)
```

```
C
C      STEP 1-NUMBER OF STANDARD HOURS PER UNIT LOAD HAS TO BE CALCULATED
C
       WRITE(6,210)
210    FORMAT(' PLEASE ENTER NUMBER OF STANDARD HOURS PER PART (SHPPTM)')
       WRITE(6,220)
220    FORMAT(' PLEASE ENTER NUMBER OF PARTS PER UNIT LOAD(NPPUNL)')
       READ(5,*)SHPPTM,NPPUNL
       SHPUNL=SHPPTM*NPPUNL
       WRITE(6,230)SHPUNL
230    FORMAT(' NUMBER OF STD HOURS PER UNIT LOAD(SHPUNL)IS',
      &2X,F7.2)
C
C      STEP 2- NUMBER OF WORK STATION FOR THE PARTICULAR PRODUCTION
C      PROGRAMME IS CALCULATED (ON BASIS OF UNIT LOADS)
C
       WRITE(6,240)
240    FORMAT(' PLEASE ENTER NUMBER OF UNIT LOADS PER HOUR(UNLPH)' )
       READ(5,*)UNLPH
       NOW=SHPUNL*UNLPH
       WRITE(6,260)NOW
260    FORMAT(' THE NUMBER OF WORK STATIONS NEEDED IS' ,2X,F7.3)
       RETURN
       END
C...
       SUBROUTINE MFAREA
C
C
C      PROGRAM FOR CALCULATION OF THEORETICAL MANUFACTURING AREA
C      (AREA FOR ALL WORK STATION MODULES REQUESTED...MANUFACTURING SPACE)
C      IN SQUARE METERS.
C
       WRITE(6,300)
300    FORMAT(' CALCULATE THEORETICAL MANUFACTURING AREA IN SQ.METERS' )
C      THE AREA IS GIVING APPROXIMATE AREA NEEDED-FOR "STUDY" AND "PPOGRAMME"
C      AND INDICATE THE SIZE OF AN "ENDLESS STRAIGHT" INDUSTRIAL BAY
C
       WRITE(6,310)
310    FORMAT(' PLEASE ENTER NUMBER OF WORK STATION SUGGESTED(NOWS)')
       READ(5,*)NOWS
       WRITE(6,320)
320    FORMAT('PLEASE ENTER AVERAGE AREA PER WORK STATION (WSAA)')
C      THE AVERAGE AREA PER WORK STATION HAS TO BE ESTIMATED ACCORDING
C\TO EXPERIENCE IN SIMILAR PRODUCTION AND WORKSHOP...OR INFORMATION
C      IS TAKEN FORM W.S.CARDS(MANUFACTURING MODULES)
C
       READ(5,*)WSAA
       MFARE=NOWS*WSAA
       WRITE(6,330)MFARE
330    FORMAT(' MANUFACTURING AREA(MFAREA)IN SQ.METERS IS',3X,F7.2)
       RETURN
       END
C...
       SUBROUTINE BAYLGH
C
C      This is"BAYLG"program for computation of a total length
C      of "CONTINUOUS" industrial bay.
C      Data :MFAREA is received from the program MFAREA
C            BAYWD  is determined width of bay according to following
C            quantitative requirements
```

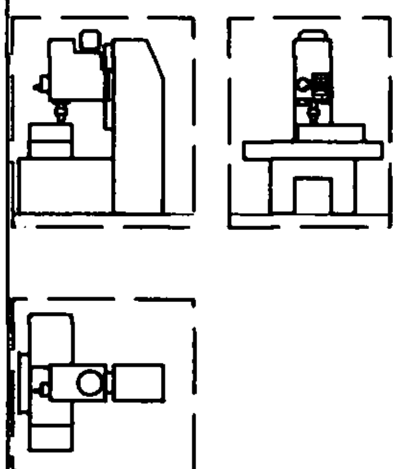
```
C             -size of Product
C             -size of an average work Station
C           -size of Aisles-Material Handling areas
C             -system of Material Handling
C             and is usually 6,9,12,15,18,21,24, etc, meters
C
         WRITE(6,400)
   400   FORMAT(' Calculate Length of "Continuous"industrial bay(BAYLG)')
C
C        The determination of sizes of the Bay is useful for graphical
C        design of work Staion in position in the bay and for decision
C        regarding dimensions of the Industrial Hall(Plot needed).
C        Maximum length of a bay should not exceed length 198 m.
C
         WRITE(6,410)
   410   FORMAT(' Please enter the size of Manufacturing Area in Sq.m' )
         READ(5,*)MFAREA
         WRITE(6,420)
   420   FORMAT(' Please enter dimension of bay width(BAYWD) in meters' )
         READ(5,*)BAYWD
         BAYLG=MFAREA/BAYWD
         WRITE(6,430)BAYLG
   430   FORMAT(' Total length of "Continuous" Bay(BAYLG)in m. is',3X,F7.2)
         RETURN
         END
C...
C...
C. .     FILE UNDER THE NAME "M100.FOR"
```

APPENDIX III

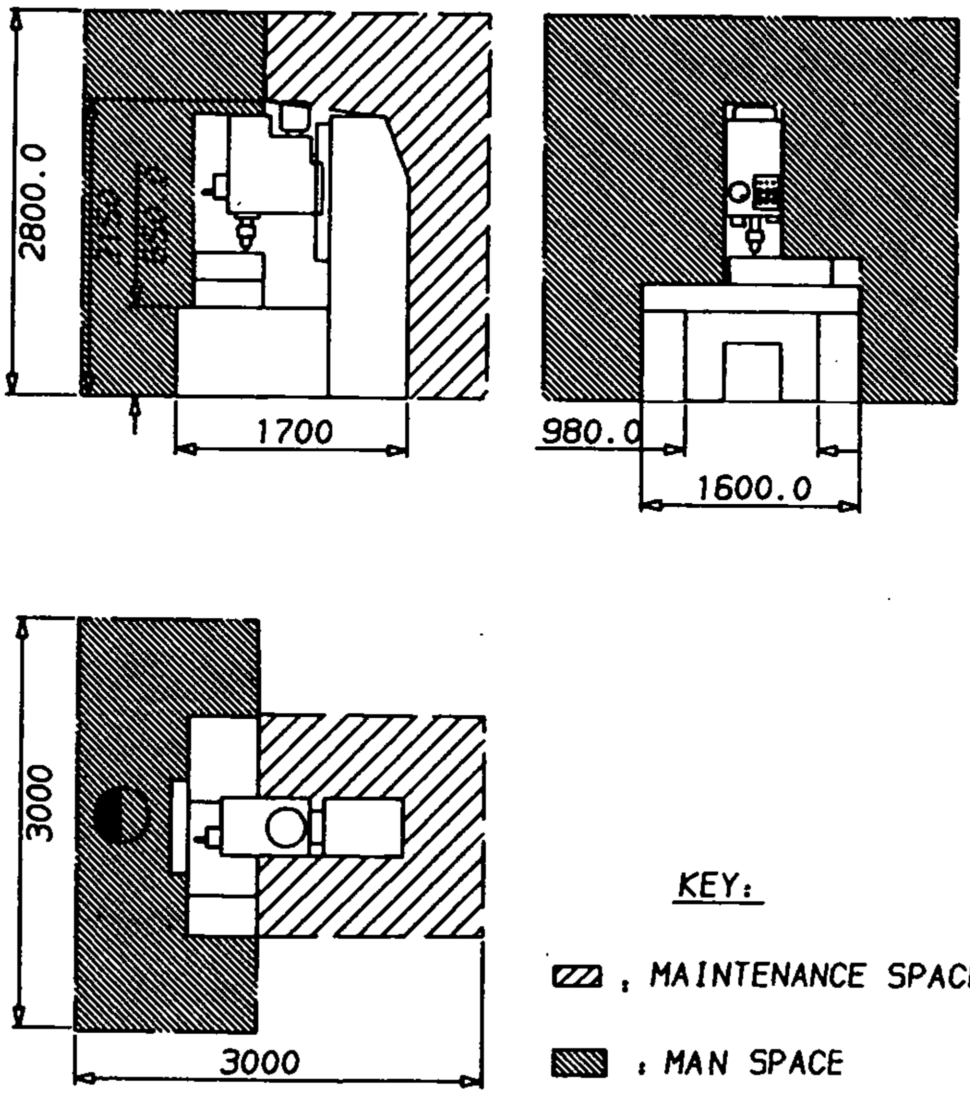
D r a w i n g No. 1.

Sheets 1 to 6

M/C NAME	M/C NO	CARD NO	POSITION	PAGE NO
GARRETT	17229248	18	CD(03-04)	001

01	CLASS NO: 17229248	07	MANUFACTURER: RICHARD GARRETT
02	DESCRIPTION: NC DRILL	08	ORDER REF:
03	COMPONENT-SUB-SYS:DIM/M PUNCHED CARD READER (0.76,0.63,1.45)	09	OTHER INFORMATION:
04	STATIC LOAD/KN 14	10	DYNAMIC LOAD/KN
05	TECHNOLOGICAL SPEC:	11	TEMPLATE FOR MSL001: 
06	REMARKS NO ANCHORING FOUNDATIONS		

M/C NAME	M/C NO	CARD NO	POSITION	PAGE NO
R.GARRETT	17229248	18	CD(03-04)	002



KEY:

▨ : MAINTENANCE SPACE

▩ : MAN SPACE

M/C NAME	M/C NO	CARD NO	POSITION	PAGE NO
R.GARRETT	17229248	18	CD(03-04)	003

SPECIFICATIONS.

A	MACHINE		
01	Maximum workpiece dimmensions (WxDxH)	mm	38
02	Maximum workpiece Weight	Kgs	
03	Front to back table travel	mm	370
04	Left to right table travel	mm	610
05	Vertical slide travel	mm	685
06	Table feed rate	mm/min	
07	Outside dimmensions (WxDxH) /m		2.1*1.6*1.6
08	Weight	kgs	
09			
10			
11			
B	POWER SUPPLY.		
01	Output voltage (.no Load)	V	380
02	Maximum machine current		1.76
03	Machine control system		YES
04	Maximum Input		
05	Outside dimmensions (WxDxH)	mm	
06	Weight	Kgs	
07			
08			
C	DIELECTRIC FLUID SUPPLY.		
01	Dielectric fluid		COOLANT
02	Tank capacity	L	30
03	Filter element		YES
04	Outside dimmensions (WxDxH) /m		0.5*0.3*0.2
05	Weight	Kgs	
06			

D	CONTROL	
01	Control axes	X, Y, Z
02	Interpolation	
03	Minimum command unit	
04	Table position display	mm
05	Block No. display	DIGITAL
06	Program capacity	NO
07	Input method	TAPE
08	Mirror Image	YES
09	X Y axis change	YES
10	Single block feed	YES
11	Dry run	YES
12	Machine Lock	YES
13	Backlash compensation	YES
14	Memory call	NO
15	Self diagnostic FCN	NO
16	Automatic positioning function	ON TAPE
17	Inch/mm display	NO
18	Outside dimmensions (WxDxH) /m	0.7*0.6*1.4
19	Weight	Kgs
20		
21		
E	REMARKS	
01		
02		
03		
04		
05		

M/C NAME	M/C NO	CARD NO	POSITION	PAGE NO
R.GARRETT	17229248	18	CD(03-04)	004

	MAINTANANCE CRETERIA	TIME INTERVALS			
		DAILY	WKLY	MTHLY	YRLY
A	MECHANICAL				
A1	CHECK & EXAMINE				
01	BEARINGS				X
02	DRIVE BELTS				X
03	SAFETY DEVICES			X	
04	M/C CALIBRATION			X	
05	TABLE ALLGNMENT			X	
06	MOUNTING BOLTS				X
07	HOSE & PIPES			X	
08					
08					
A2	CLEAN & LUBRICATE				
01	MOVING PARTS	X			
02	MOVING SURFACES	X			
03					
04					
A3	REPLACE				
01	DRIVE BELTS				X
02	BEARINGS				X
03					
04					
05					
B	ELECTRICAL				
B1	CHECK & EXAMINE				
01	CONTACTORS			X	
02	AUTOMATIC CONTROLS			X	
03	FUSES			X	
04	BRUSHES			X	
05	CHARGE COILS			X	
06					
B2	CLEAN				
01	CONTACT POINTS			X	
02					
03	REPLACE				
04					
05					
C	HYDRAULIC				
C1	CHECK & EXAMINE				
01	OIL LEVEL		X		
02	OIL FILTERS		X		
03	PIPES & VESSELS			X	
04	PUMP BEARINGS				X
05					
C2	CLEAN				
01	OIL FILTERS			X	
02					
C3	REPLACE				
01	OIL			X	
02	OIL FILTERS				X
03					

REMARKS

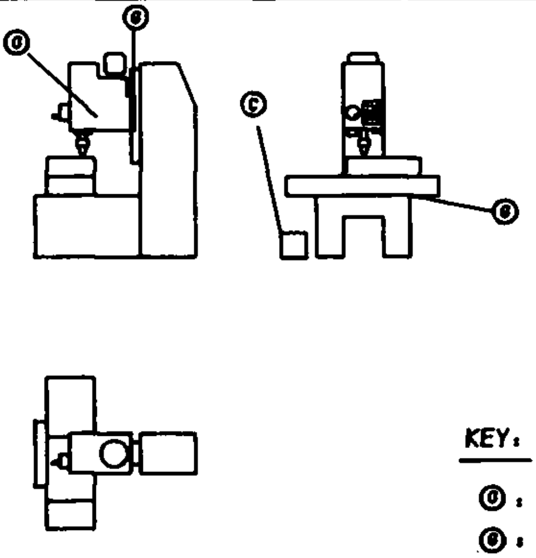
PLACE X IN APPROPRIATE TIME SCALE

NOTE:

OVERHAULL ONCE EVERY YEAR

M/C NAME	M/C NO	CARD NO	POSITION	PAGE NO
R.GARRETT	17229248	18	CD(03-04)	005

		A	B	C
		TYPE	CONSUMPTION /MONTH	QUALITY
001	OIL	SHELL VIERRA OIL 69	DEPENDS ON USAGE	GOOD
002	GREASE	ALVANIA GREASE NO.2	DEPENDS ON USAGE	GOOD
003	COOLANT	MINERAL OIL	DEPENDS ON USAGE	GOOD
004	HYD.OIL	/	/	/
005				



KEY:

Ⓞ: OIL

Ⓖ: GREASE

Ⓒ: COOLANT

M/C NAME	M/C NO.	CARD NO.	POSITION	PAGE NO.
R.GARRETT	17229248	18	CD (03-04)	006

INSTALATION DETAILS

A	MACHINE DETAILS		
01	MANUFACTURER	R.GARRETT	
02	MACHINE TYPE	NC DRILL	
03	MACHINE MODEL	TD.251S	
04			
05			
B	MACHINE DIMENSIONS		
01	Height	mm	2.1
02	Width	mm	1.6
03	Depth	mm	1.6
04	Weigth	kg	1100
05	Loads	KN	
C	FLOOR REQUIREMENTS		
01	Type of Floor	CONCRETE	
02	Method of Fixing		

D	HANDLING REQUIREMENTS		
01	Crane Maximum Lift	kg	
02	Fork Lift Truck		
03	Others		
E	AUXILLIARIES		
01	Water	YES	
02	Power	YES	
03	Lubricating Oil	YES	
04	Coolant	YES	
05	Gas	NO	
06	Waste Removal	YES	
F	OTHERS		

DRAWING OF FOUNDATION FLOOR

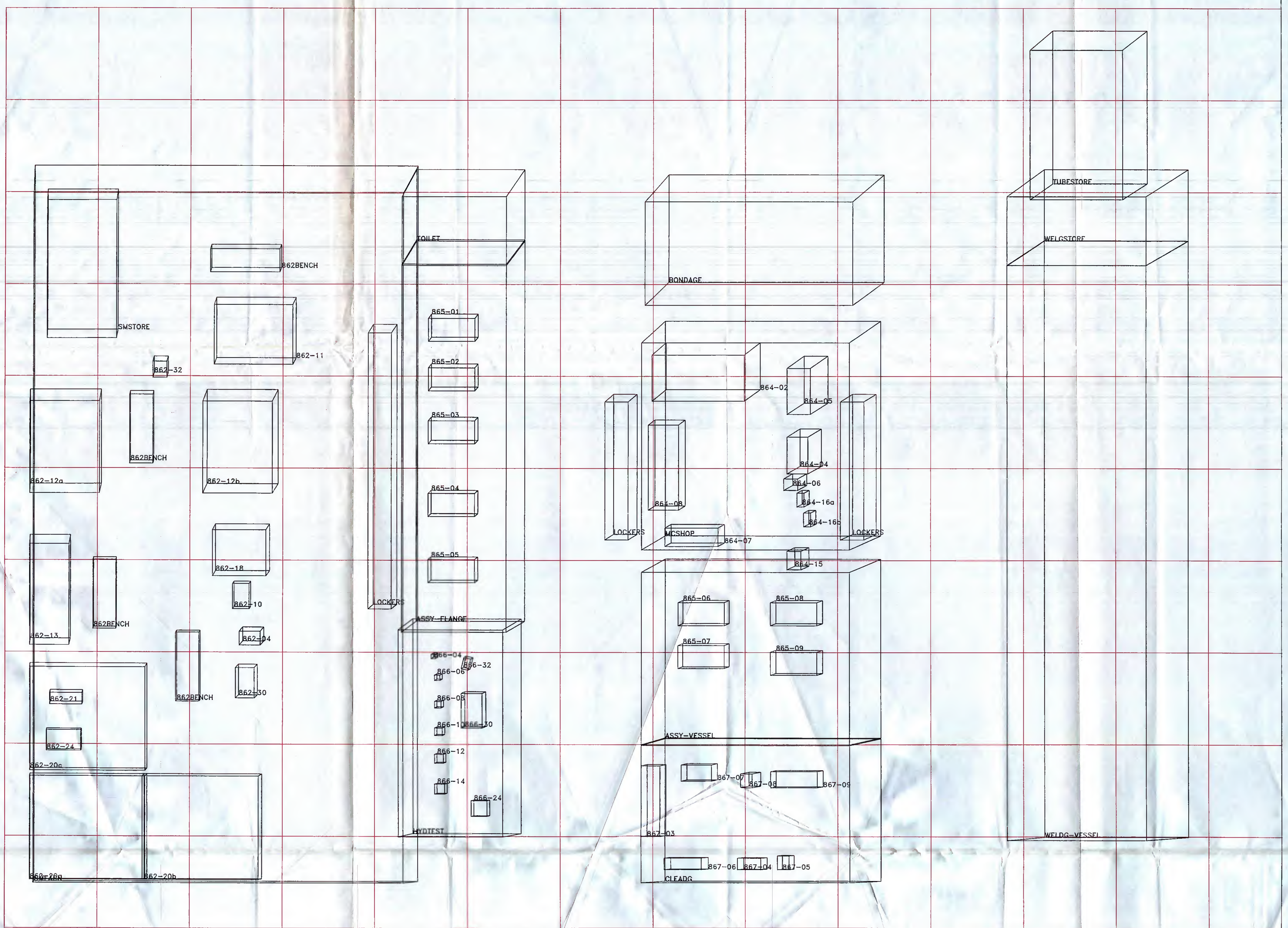
NO ANCHORING FOUNDATIONS

D r a w i n g   No. 2.

Drawing No. 3.

ELTRON (LONDON) LTD.

DETAIL LAYOUT II



ELTRON (LONDON) LTD.

DETAIL LAYOUT II